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ARE SCALES AN INDEX TO THE AGE AND GROWTH OF HILSA ? ¹

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INTRODUCTION.

Scale reading is a comparatively recent and highly specialized branch of Fishery Research. A reasonably precise knowledge of the stock of fish, i.e., a census of the fish population classified into 'year classes' is essential for fisheries research and administration. In this paper an attempt is made to assess the age of Hilsa by certain markings on its scales.

In confined waters, where the fish are under control, the direct counting of stock and the reckoning of age and rate of growth by actual observation are possible. For most sea and even river fish such direct evidence is unobtainable, except to a limited extent by 'tagging' and the estimation of age and numerical strength is possible only by indirect methods. One such is the well-known Peterson method first propounded in 1895 which employs growth frequencies of random samples covering the full range of sizes of a fish. Other methods include the examination of scales, opercular bones or sections of otoliths, vertebrae and fin rays for annual growth rings. The scale method of age determination is the most widely used method at present. In clupeids, such as Hilsa, scales afford the best indirect evidence of age.

That the scales of certain fish afford evidence of their age has been known since the time of Anthony Von Leeuwenboek (1696)—well over 250 years. He cut sections of carp scales and wrongly interpreted each layer or lamella as representing a year in the life of the fish. Reaumur (1716) was the first to suggest that the markings on the scale give an indication of the rate of growth of the fish. To Mandl (1839) and Williamson (1849) we owe the distinction that is now drawn between the striated upper layer and the fibrous lamellated lower layer in fish scales. Steenstrup (1861) was the first to observe that all scales except placoid grow throughout life proportionately to the size of the fish. This is the basis of age determination by means of scales. Modern fish scale reading is confined to the upper striated layer except when polarized light is used for the elimination of false rings. However, it was not till the nineties that Haffbauer (1899) revived interest in scale reading. He experimentally proved that favourable and unfavourable seasons affected scale growth in the carp and caused the formation of annual rings by which it was possible to determine the age of the fish. Hoffbauer thus laid the foundation of this important line of research in fishery science and the principle has since been applied to several other food fish, notably the Salmon, Cod and Herring.²

During the last half century, the subject has received considerable attention from fishery investigators all over the world, particularly in Norway. The theory as well as the technique of scale investigation have been gradually developed in spite of adverse criticism and even scepticism and is now an approved and well developed method of fishery research which yields results of considerable precision otherwise unobtainable. The main theory is (1) that annuli or yearly growth rings are formed on scales, except in the tropics, as a result of varying temperature, amount of food

¹ This paper was read at the 33rd session of the Indian Science Congress, Bangalore, 1946.

² Even in temperate water, if food is available, fish continue to grow as proved by the well-known manuring experiments of Gross and Rayment in Scotland.

or other still obscure physiological causes and so their number is a record of the age of the fish, (2) that the length of the scale bears a constant proportion to the length of the fish in all stages of growth, except the earliest before the scales are formed. The rate of growth of the fish can thus be ascertained by the relative position of the annual rings on its scales. Age determination and growth determination are thus the two main aims of scale reading in modern fishery research.

Hilsa SCALES.

In shape and markings, scales differ in different groups of fish. Even in the same fish the scales are not of the same shape in the different parts of its body. It is customary to use only the shoulder scales which are the best developed for scale reading. In *Hilsa*, scales are discernible when the fry attain 40 mm. or 1.6" in length. For scale reading, scales from fish of 4.5" (115 mm.) onwards are suitable as those from younger fish show hardly any markings. A fully formed dorso-lateral (pectoral) scale of an adult *Hilsa* is subquadrate in shape (Plate I). In markings the *Hilsa* scale is typically clupeid in character. The small apical or posterior field is sharply separated from the basal or anterior region. The apex is pellucid and without circuli and has numerous horizontal radii, which tend to make the apical margin somewhat dentate. In the young the apical radii are few. In the very young only beginnings of the radii are noticeable on the nucleus border. The basal or anterior field of the scale is covered by exceedingly fine circuli (Plate I, fig. 1B) which do not seem to have any relation to the many indistinct rings of growth. The two striking features of *Hilsa* scales are:—(1) In the adult fish the circuli are not absolutely transverse but tend to follow the contour of the basal margin, and do not reach the lateral margins of the scale at right angles or even obliquely, as in most clupeids. (2) Everywhere, except in the apical and nuclear regions, the scale is traversed by undulating roughly parallel transverse grooved lines (Radii) at more or less regular intervals. Most of the outer 'grooves' reach the lateral margins of the scale obliquely. Those nearest the nucleus, however, pass into the apex on either side of the nucleus as horizontal apical radii. These transverse grooves, therefore, have been rightly identified as radii by Baudelot (1873) and later by Cockerell (1910). As a rule, the transverse radii in *Hilsa* scales are entire. Some are, however, incomplete or interrupted in the middle. Some in the centre of the scale anastomose and in rare cases form an irregular network.

GROWTH RINGS IN *Hilsa* SCALES NOT ANNUAL.

Even in the smallest scale examined from *Hilsa*, hardly a few weeks old, two or more delicate concentric 'lines of growth' occur (Plate II, fig. 2) which are indistinguishable in appearance from the recognized annual growth rings or annuli in Herring scales of Europe and America. In the young, as well as adult *Hilsa*, these rings are too numerous to be annuli and do not occur at regular intervals. Evidently there are frequent checks to the growth of *Hilsa* or its scales which cause the formation of these growth rings about which little is known. Another significant feature is the occurrence of double rings on some *Hilsa* scales which were examined by experienced scale readers both in Liverpool and Norway. The significance of this is also unknown. Prasad, Hora and Nair (1940) commenting on the growth rings of *Hilsa* scales in Bengal stated in 1940, 'We believe that they are formed not at regular intervals but whenever conditions of life become unfavourable'. These growth rings on *Hilsa* scales are too numerous to be considered annual growth rings or 'annuli'. Consequently they cannot in the present state of our knowledge provide any evidence of age or rate of growth and must be discarded. This seems to be true also of other tropical fish. Thus to the fishery investigator in India this important clue to the age and rate of growth of fish is denied.

TRANSVERSE RADII INDICATE AGE OF *Hilsa*.

On examining the other markings on *Hilsa* scales it was noticed that the transverse radii in the *Hilsa* scale occurred at regular intervals and increased in number more or less proportionately with the age and size of the fish notwithstanding its provenance. I suggest that these afford a clue to the age of *Hilsa* and possibly to their rate of growth. Scales from some 500 specimens of different sizes from all over India have been studied. As in other fish, the dorso-lateral scales of the pectoral region are the best developed and were found to give reliable numbers of radii while those of the caudal peduncle are as a rule poorly developed and usually had more transverse radii which however were not constant. For the statement below only the normal dorso-lateral scales of the pectoral region have been taken into account. Both complete and incomplete transverse radii were counted since incomplete radii, by their relative position in the regular series, deserved to be taken into account.

The statement below summarizes my studies extending over a number of years on *Hilsa* scales from Bengal, Madras, Bombay, Sind and U.P. waters and a specimen from Iraq.

Overall length of fish in inches.	No. of transverse radii counted.	No. of radii mostly seen.	Age actually counted or estimated.
4"- 5"	2-4A	2 or 3	<i>From the river or tank</i> —1st year. (Actually ascertained from rivers and confined waters.) Mostly from Pulta Water Works, Calcutta, the Sundarbans, lower reaches of the Cauvery and Godavari rivers and connected tanks after the monsoon floods.
5"- 6"	2-6B	3 or 4	
6"- 7"	3-5	4 or 5	
9"-11"	5-9A	6 or 7	
12"- 13"	8-12A	9 or 10	<i>From the river and tank</i> —2nd year. (Actually ascertained from rivers and confined waters†.) From the lower reaches of the Cauvery, Krishna and Godavari and connected tanks.
13"-14"	8-13A	9 or 10	
14"- 15"	11-14A	9 or 12	
15"- 16"	11-17A	12 to 17*	
16"-17"	13-17B	14 to 17	
17"-18"	13-17A	12 to 17	
18"-19"	11-18A	13 or 14	<i>From the sea ascending rivers to spawn</i> —3rd year or older (estimated.) From the Cauvery, Krishna and Godavari rivers during the monsoon floods.
19"-20"	11-20B	13 to 16	
20"-21"	15-27†	16 to 18	

A & B.—The maximum number of radii in these groups is also the number of inches in the length of the fish.

* 17 radii on most scales of a *Hilsa* measuring only 15"-16" is unusual and is due probably to some error in counting. As the scales have been lost this cannot be checked.

† When the number of radii is as large as 25 to 27 a greater age than 3 years is probably indicated.

‡ Specimens from Calcutta Water Works tanks and some tanks in Madras.

4" - 5". This means sizes from 4" to just short of 5".

The largest male and female fish examined measured 21 inches or 654 mm. in length (overall). Messrs. Chacko and Ganapathi (1949, p. 17) have recorded a female 23.5" long but have not described its scales. The fish whose age is known, from the Calcutta Water Works and from some tanks in Madras, have been compared, size for size, with fish taken from open rivers and the sea and scales of both were found to possess the same average number of radii.

In the statement the fish have been arranged in groups differing from one another by one inch. The collection studied was not quite complete. For instance,

there are no fish of the size 7" to 8", 8" to 9", round about 10" and 11" to 12". The number of fish in each group also varied enormously. Nevertheless, there is an intelligible correlation between the number of inches in col. 1 and the number of radii in col. 2 of the statement. In 7 out of 13 groups marked A, the maximum number of radii is the minimum number of inches; in three groups marked B the maximum number of radii is the maximum number of inches. Messrs. Chacko, Zobairi and Krishnamurthi (1948) have confirmed this observation after examining 1,100 specimens and have ventured to estimate the age in months:

TRANSVERSE RADII AND GROWTH RATE OF *Hilsa*.

The intervals between the radii, though slightly smaller towards the margin of the scale, seem to me to be too uniform to provide data for calculating the rate of growth, unless it is proved that *Hilsa* grows more or less uniformly till it attains maturity. Cultural experiments in tanks and many more counts than are recorded in this paper will be needed to settle this relationship satisfactorily.

DISCUSSION.

I am aware that I am suggesting a significance to radii in fish scales which may be unacceptable to the conventional scale reader. Few authors have suggested the use of radii for estimating age. Baudelot in 1873 observed that the number of grooves (concentric or transverse radii) of an individual scale is capable of varying with age. Taylor (1916)¹ discusses in detail the use of radii in age determination of fish. At page 304 he states as follows:—

'The different means of determining age with more or less accuracy are:

(1) A count of the annuli aided by—

- (a) Polarized light.
- (b) The selective action of picrocarmine stains.
- (c) The origins of the radii.

(2) Identification of year groups by measurements of length and weight.

These methods may be used in combination.'

At pages 309 to 310 he observes that the radii are only supplementary to the annuli as a means of age determination.

'The origins of the radii.—Like polarized light and picrocarmine stain, the radii are only supplementary to the annuli as a means of age determinations.

As in the majority of teleosts, radii appear on the scale of *Cynoscion regalis* only on the anterior side. They begin, usually four to six in number (on the sides of the fish), at about the seventh circulus, counting from the focus. These usually continue to the periphery. As the scale increases in size, more radii are added on either side of those first appearing beginning at various distances from the periphery. Proceeding laterally from the long axis, one finds that they extend diminishing distances from the periphery. They are usually symmetrically arranged—i.e. a radius beginning on one side of the axial radius will correspond with a similar radius beginning at the same distance from the periphery on the other side. The points at which radii begin in the main coincide with the annuli. It would, then, be a simple matter to count these points to determine age, but this rule is by no means infallible. Radii often begin between two annuli, and sometimes continue for a short distance only and then disappear. But radii beginnings, notwithstanding this variability are sufficiently constant to afford a valuable means of verifying and supplementing the other methods.'

At page 316 he concludes—

'Age may be determined in two ways: (1) by counting the annuli, the count being facilitated by (c) beginnings of radii; (2) by year groups in length and weight.'

As no regular annuli occur in *Hilsa* scales, radii are the only indication of age and an attempt is made in this paper to use them *exclusively* for the determination

¹ I owe this reference and the loan of Taylor's paper to Dr. S. L. Hora.

of age. Also no author to my knowledge has suggested the use of radii for determining rate of growth as is done in this paper.

As radii normally radiate from the centre to the periphery of a scale they usually give no indication of the rate of growth of a fish. In most clupeid scales the anterior radii are transverse but are not as numerous or as regularly spaced as in *Hilsa*. Describing transverse radii in clupeid scales, Cockerell mentions 7 or 8 transverse radii in all widely broken in the middle except the first, in the pilchard; 5 in *Opisthonema*; 2 or 3 in *Sardinella* and only 2 in *Baetodortia*. In the adult *Hilsa*, measuring 21 inches, 11 have counted as many as 27 radii.

It is true that growth rings or annuli actually show the outline of the scale at successive stages of growth, whereas transverse radii in the *Hilsa* scale have no such known significance. But in the absence of recognizable annuli, the transverse radii in *Hilsa*, the number of which are fairly constant for a given length of fish, will, I hope provide some evidence of age and even possibly of growth of *Hilsa* where at present such evidence is lacking. The correlation between the number of transverse radii, and the actual size and age of *Hilsa* can be worked out more or less accurately up to the adolescent stage from the young *Hilsa* entering tanks, and residing in the rivers before proceeding to the sea. From tanks connected with the Cauvery in Madras and with the Ganges in Bengal we have collections of young *Hilsa* whose exact age up to 2 years is definitely known, and from whose scales the number of transverse radii corresponding to the age and size of the fish was counted. This was checked by simultaneous collections from the rivers Cauvery and Godavary. On this data available up to 2 years the age of the adult *Hilsa* returning from the sea to breed and whose age is unknown, was deduced (vide statement above). Direct proof of age for confirmation will only be available after tagging experiments on sea-going *Hilsa*, suggested by me (1930-31, p. 32) are carried out. In 1925-36 investigations in Madras waters showed that *Hilsa* take 2 years to grow to the adult size and reside in the estuaries of rivers for this period. In Bengal fish of 12 cm., i.e. one year old fish, have been found in the open sea, due probably to the perennial influx of fresh water and the estuarine conditions prevailing in the sea not found along the Madras coast. I stated at that time 'the period they spend at sea and whether they breed more than once in rivers and the age limit of the fish remain yet to be discovered' (1935-36, p. 38). My scale studies on *Hilsa* seem to suggest that normally only the third year is spent at sea by most *Hilsa* before they return to the river to breed. The average of the maximum number of transverse radii (col. 3 of the statement) usually seen in the first year is 7, in the second year 14, and in breeders returning to the rivers apparently three years old. 18. Though some half grown males, apparently a year old, may be in milt and take part in spawning before going to sea. This has been recorded also for Salmon (Meek, 1946). A few full grown fish, however, seem to survive to a greater age as the radii in their scales reach a maximum of 27. This indicates a longer life than 3 years for the fish, and the breeding of such fish more than once, as they were taken in the Godavery river during monsoon floods.

There is some doubt as to the extent to which these transverse radii provide evidence of the rate of growth, as they are regularly spaced except a few peripheral ones. Evenly spaced radii must be presumed to indicate a uniform rate of growth of the scale and therefore of the fish. Of this there are other indications, for instance the maximum number of transverse radii generally corresponds with the number of inches in the length of the fish except in very large specimens (vide cols. 1 and 2 of the statement) and the transverse radii though evenly spaced are progressively closer to each other towards the periphery, indicating a gradually slower rate of growth as age advances. In a specimen from Iraq measuring 13.8 inches in the Indian Museum collection, 13 radii were found which conforms to the average number on scales of Indian fish of the same size and age. The growth, after the fish have attained adult size of about 20 inches, is very slow or imperceptible, as in most

adults. This is shown by the disproportionately large number of radii (27) compared with the length of the fish in inches (21 inches). A more intensive study of the scales correlated with age in addition to tagging experiments is required before the evidence regarding the rate of growth of *Hilsa* from its scales can be finally accepted.

An intensive study of all the available characteristics of scales of other tropical fish besides the accepted 'growth rings' may provide evidence of their age and growth as in *Hilsa*.

SUMMARY.

A census of fish populations classified according to age is essential for fishery research and administration. A brief history is given of scale investigation which is now a recognized method of research in fishery science. Scales specially of clupeid fish provide, by annual growth rings, indirect but reliable evidence of age and rate of growth, otherwise unobtainable. In the tropics however growth rings even when present fail to furnish any intelligible evidence of age or rate of growth.

The *Hilsa* scale is described in detail. In *Hilsa* the growth rings are too numerous and ill defined for the estimation of age, but the transverse radii in the anterior region of the scale which are regular and well defined, was found to provide evidence of age. From *Hilsa* grown in tanks in Bengal, and Madras, whose age was known up to 2 years, the average number of transverse radii was found to correspond more or less with the size of the fish in inches. The scales of a large number of *Hilsa* from the river and sea from the east and west coast of India and Iraq, when examined were found to bear the same constant relation to the size of the fish, except in the full grown fish. It is, therefore, suggested that the radii in *Hilsa* scales should be used for age determination.

Evenly spaced radii seem to suggest uniform growth, but further study is required to establish this. The suggestion is also made that all available characters of scales besides the conventional growth rings, if studied, may throw light on the age and rate of growth of other tropical fish.

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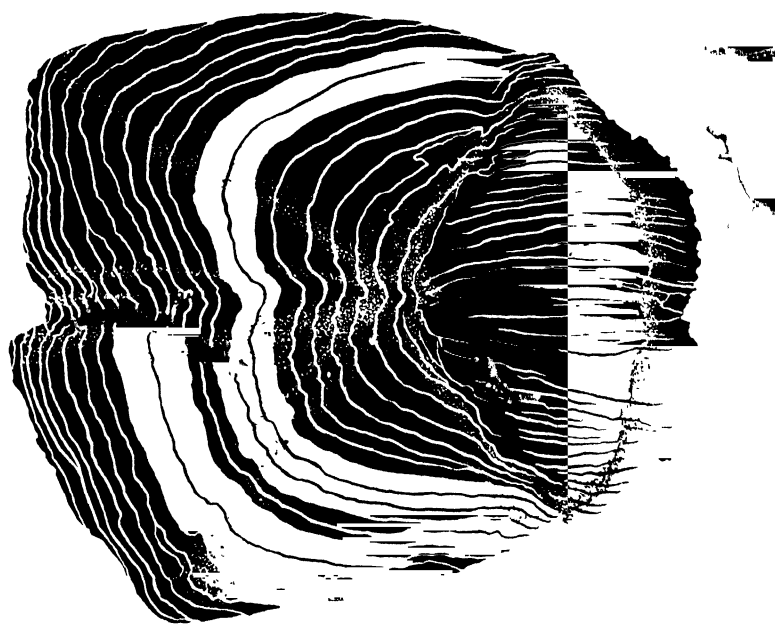


FIGURE 1A.

Scale of an adult male Hilsa 21 inches long showing 27 transverse rings.



FIGURE 1B.

Part of the small scale enlarged to show the fine circles.



FIGURE 2.

Photo of small-scale from a young Hilsa measuring 4.6 inches showing growth rings in addition to transverse radii and circuli.

DICTYOZAMITES BAGJORIENSIS SP. NOV. FROM THE MESOZOIC OF
RAJMAHAL HILLS, WITH NOTES ON THE DISTRIBUTION OF THE
GENUS.¹

By K. L. SAHNI, D.Sc., F.G.S., F.N.I., Geological Survey of India.

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I. INTRODUCTION.

The specimens described in this short paper were collected from Bagjori (25° 06': 87° 44'), a locality seven miles south of Maharajpur (25° 13': 87° 45') in the Rajmahal Hills, Bihar. Besides the specimens described here as new, good impressions of *Dictyozamites halli* Sahni and Rao (1933) and *Marattiopsis macrocarpa* (Morris) were the only other forms obtained.

II. DESCRIPTION.

DICTYOZAMITES Oldham,

Dictyozamites bagjoriensis sp. nov. (Plate I, figs. 3-5).

The specimens of this species obtained from Bagjori are the impressions of slender pinnate fronds. Only one specimen is figured here, the preserved length of which does not exceed 4 cms. The breadth of the frond is about 2.5 cms. In general habit the fronds resemble *Ptilophyllum* or *Otozamites*.

The rachis is very slender, about 0.5-0.75 mm. in width; the sub-opposite pinnae are attached at wide angles to the upper face of the rachis by a small portion of the lamina slightly below the middle of the base. In the figured specimen, however, the pinnae are opposite in the upper part of the frond and sub-opposite in the lower part. The angle of attachment to the rachis is also wider towards the upper part, about 70°, and narrower towards the base (55°).

The pinnae are usually a little over 1 cm. in length, rather long and narrow in shape, slightly falcate with a somewhat gently curved lower margin tapering gradually to a bluntly rounded apex. The base of the pinnae is not completely visible, but it appears that the base was probably auriculate.

The veins are very few, distinctly radiate, arising from the region of attachment of the pinnae, and not more than six veins being present at the base. The veins later bifurcate; sometimes, bifurcation usually twice before reaching the margins of the pinnae. Not more than five veins (usually four) are crossed at the middle of each pinna. The basal midrib areolae are about 4-5 mm. long and less than 0.5 mm. broad. The number of veins reaching the lower margin of the pinnae is six.

III. COMPARISON.

In its general habit and to some extent in the shape of the frond the closest resemblance of this frond from Bagjori is with *D. halli* Sahni and Rao (1933) so far known only from Onthea in the Rajmahal Hills; but it differs from *D. halli* Sahni and Rao (Pl. III, figs. 1, 2) in the following features:—

1. The frond is more slender with the pinnae generally shorter, and broader at the base.

¹ Published by permission of the Director, Geological Survey of India.

2. The veins distinctly radiate from the base (cf. the parallel course of the middle veins in *D. hallei*).

3. Not more than five, or occasionally six veins are present at the base of the pinnae (cf. 8 or 9 in *D. hallei*).

4. Only 4 to 5 veins are crossed in the middle of each pinna (cf. 7 or 8 in *D. hallei*).

5. The number of veins reaching the lower margin of the pinnae is usually 6 (cf. about 18 or more in *D. hallei*).

It is considered that the differences enumerated above are of sufficient specific importance (and not mere variations of the typical *D. hallei*), to justify the institution of a new species. It is described here under the new name *D. bagjoriensis* after the locality.

A specimen of *D. hallei* Sahni and Rao, is also figured here in Pl. III, figs. 1, 2, primarily for comparison with *D. bagjoriensis* sp. nov. The specimen shows some interesting distinction from those figured by Sahni and Rao (1933) particularly in the lower margin of the pinnae. The marginal veins, probably owing to the nature of preservation, appear unusually prominent than those in the rest of the pinnae, giving a serrated appearance to the margin. The lower half of the auriculate base is also much pronounced. Otherwise the frond is identical with *D. hallei* Sahni and Rao. The other species of *Dictyozamites* described from India are *D. falcatus* (Morris) and *D. indicus* Feist., both of which are quite distinct from *D. bagjoriensis* and merit no detailed comparison. The species of *Dictyozamites* occurring outside India and mentioned elsewhere in this paper while discussing the distribution of the genus, are totally different from *D. bagjoriensis*.

Horizon.—Rajmahal stage (Middle Jurassic), Upper Gondwana.

Locality.—Bagjori, 7 miles S. of Maharajpur, Santal Parganas, Bihar.

IV. DISTRIBUTION OF THE GENUS (see Text-fig. 1).

The following is a list of species so far described:—

(1) *Dictyozamites falcatus* (Morris).

India.—*D. falcatus* (Morris) from the Rajmahal stage (Middle Jurassic), Rajmahal Hills (Oldham and Morris, 1863; Feistmantel, 1877). Upper Gondwanas, Madras Coast (Feistmantel, 1877a, 1879).

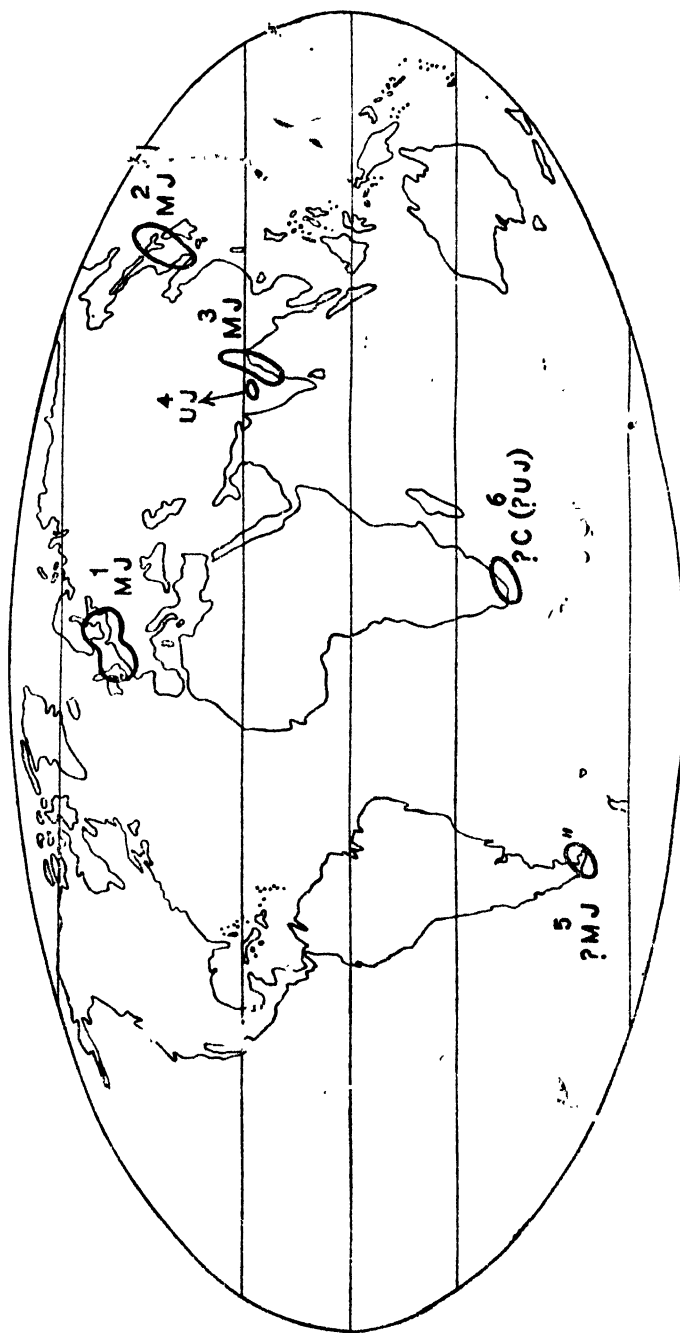
Japan.—*D. falcatus* var. *distans* Yok. from the Tetori series (? Middle Jurassic) of Central Japan (Yokoyama, 1886).

Korea.—*D. falcatus* (Morris) from the Jurassic (? Middle Jurassic) of Korea (Yabe, 1905). Yabe considers the specimens as probably a variety of the species.

Tierra del Fuego, S. America.—*Dictyozamites* cf. *falcatus* (Morris) from the Jurassic, most probably the Middle Jurassic of Bahia Tekenika (Halle, 1913).

(2) *Dictyozamites indicus* Feistmantel.

Feistmantel (1877, 1877a) who recognised only one species substituted the name *D. indicus* for all specimens of *Dictyozamites* including both the large and the smaller fronds then known, although Morris (1863) had described the fronds first under *Dictyopteris falcatus*. Feistmantel's reasons for discarding the name *falcatus* were considered inadequate by Seward (1903). He re-instated Morris' original specific name but included all the Indian fronds then known in a single species, *D. falcatus*. Sahni and Rao (1936) correctly distinguished two definite species, namely *D. falcatus* (Morris) and *D. indicus* Feist., including the smaller fronds described by Feistmantel



TEXT FIG. 1.

Map showing the distribution of *Dictyoconites* :

1. Middle Jurassic of Yorkshire and Bornholm.
2. Middle Jurassic of Formosa and Central Japan.
3. Middle Jurassic of the Rajmahal Hills; Jurassic of East Coast.
4. Upper Jurassic of the Satpura region.
5. Middle Jurassic of Tierra del Fuego, South America.
6. ?Uppermost Jurassic (?Lower Cretaceous) of South Africa.

?C = ?Cretaceous; MJ = Middle Jurassic; UJ = Upper Jurassic.

(1877, 1879) from Murero and the Madras Coast in the latter species and referring the larger forms to *D. falcatus* (Morris).

India:—*D. indicus* Feist. from the Rajmahal stage (Middle Jurassic) of the Rajmahal Hills (Feistmantel, 1877; Sahni and Rao, 1936).

D. indicus Feist. from the Upper Gondwanas, Madras Coast (Feistmantel, 1879).

D. indicus Feist. from the Jubalpur stage (Upper Jurassic) of Parsapani, and Jatamao and Morand rivers of the Satpura (Crookshank, 1936).

Crookshank incorrectly refers the genus to the Filicales. Oldham as early as 1863 had recognised its true nature as a cycad-like plant and instituted the name *Dictyozamites* in preference to *Dictyopteris*, a genus in which Morris (1863) had included the fronds wrongly attributing a filicenean affinity. Nathorst (1907), Flotin (1931), and Thomas and Bancroft (1913) have already demonstrated the Bennettitalean nature of *Dictyozamites* frond as a result of cuticular study.

It is also not known if Crookshank (1936) has referred his fronds to *D. indicus* Feist. in agreement with the views put forward by Feistmantel who, discarding the specific name *D. falcatus*, referred all *Dictyozamites* which were then known to *D. indicus*. I am unable to settle this point as the specimens are not available for examination.

(3) *Dictyozamites hallei* Sahni and Rao.

India:—From the Rajmahal stage (Middle Jurassic) of Onthca, Rajmahal Hills (Sahni and Rao, 1936); and Bagjuri mentioned in this paper.

(4) *Dictyozamites bagjoriensis* sp. nov.

India:—From the Rajmahal stage (Middle Jurassic) of Bagjori, Rajmahal Hills, described in the present paper.

(5) *Dictyozamites grossinervis* Yokoyama.

Japan:—From the Tetori series plant beds (Bathonian or somewhat older) of Ozo, Kaga province; and Ushimaru, Hida province of Central Japan (Yokoyama, 1886).

Seward considers this species as a variety of *D. falcatus* and prefers to refer them to *D. falcatus* var. *grossinervis*. After a careful study of Yokoyama's figures and descriptions, I am inclined to consider the species as distinct.

(6) *Dictyozamites johnstrupi* Nathorst.

Scandinavia:—From the Liassic of the island of Bornholm in the Baltic sea (Nathorst, 1889).

(7) *Dictyozamites havelli* Seward.

England:—From the type formation of Middle Jurassic—L. Oolitic of Yorkshire, England (Seward, 1903).

(8) *Dictyozamites* sp.

S. Africa:—From basal part of the Uitenhage series (? Wealden or topmost Jurassic) of the Gamtoos valley and Umgazana, Pondoland, Cape Colony (Du Toit, 1939).

The specimens, not specifically identified by Du Toit, are the only occurrence so far known of the genus in doubtful Cretaceous, if we accept the age of the basal Uitenhage as Weald.

V. ~~SOME~~ COMMENTS ON THE DISTRIBUTION OF THE GENUS.

Geographical.

INDIA :—It would appear from the above list that the genus *Dictyozamites* had a discontinuous distribution during the Mesozoic as already pointed out by Seward (1931). India with four species known so far was probably the centre of distribution with the Rajmahals as the most important area where all the Indian species were represented. South-westwards in the Upper Gondwana sediments of the East Coast, *D. falcatus* (Morris) and *D. indicus* Feist. are known. In the Jabalpur area, in the Jabalpur stage (Upper Jurassic), the genus has been recently reported by Crookshank (1936). In the Umia stage of Cutch, the topmost part of the Upper Gondwanas in India (L. Cretaceous), the genus is unknown. (See also Sahni, 1921, 1926, Tables).

EASTERN ASIA :—Another minor centre of distribution was the Far East where two species, namely, *D. falcatus* var. *distans* Yokoyama and *D. grossinerris* Yokoyama, occur in the Tetori series of Central Japan (Yokoyama, 1886), and *D. falcatus* (Morris) in the Jurassic of Korea (Yabe, 1905).

NORTHERN EUROPE :—In northern Europe, rather fragmentary finds of *D. johnstrupi* Nathorst have been reported in the Liassic of Bornholm (Nathorst, 1886). *D. hawelli* Seward occurs in the type formation of Middle Jurassic—Lower Oolitic of Yorkshire, England (Seward, 1903).

S. AFRICA :—The genus has also been recently recognised by Du Toit (1929) in the Uitenhage series of S. Africa.

OTHER AREAS :—So far as I am aware the genus is entirely unrepresented in the Australian Mesozoic and no reliable record of the genus is known to me from N. America. It is difficult to explain the discontinuous distribution of this typical Jurassic Bennettitalean representative. If it is considered that India with the largest number of species reported, was the centre of distribution of this genus from where it migrated north-westwards to northern European regions like Bornholm and England and north-eastwards to Japan and Korea, it is difficult to explain the absence of any record in the Mesozoic sediments of Central Europe and Asia. Likewise, in the southern hemisphere, if the distribution of the genus were to be attributed to the existence of the continuous land-mass of Gondwanaland, its absence from the Australian Mesozoic would remain equally intriguing. The possibility of its evolution independently in the different centres is worth consideration.

Geological.

A characteristic Middle Jurassic genus :—The genus may be said to have had a restricted geological range. It was mostly confined to the Jurassic, except for the doubtful record of its occurrence in younger strata in South Africa. Most of the other records seem to indicate that the genus was characteristic of the Middle Jurassic floras (Seward, 1917; Halle, 1913). *D. hawelli* Seward, the solitary record of the genus in England, occurs in the type formation of Middle Jurassic—Lower Oolitic of Yorkshire (Seward, 1913). So far as I am aware, *D. johnstrupi* Nath. is the only species recorded from continental European area and the beds in which the species occurs were considered by Nathorst (1889) to be Liassic or doubtfully Rhaetic, Halle (1913) however mentions that the sediments also 'contain a considerable number of species identical with such from the Middle Jurassic of England and other

countries'. On the evidence based on his *D. cf. falcatus* (Morris) Halle (1913) refers the Tierra del Fuego plant beds with some reservation to the Middle Jurassic.

D. falcatus var. *distans* Yok. and *D. grossinervis* Yok. both from the plant beds of the Tetori series of Central Japan are considered to be Zathonian by Yokoyama (1886) and believed to be somewhat older (but within the Middle Jurassic) by Halle (1913). Regarding the occurrence of *D. falcatus* (Morris) from the Jurassic of Korea, Yabe (1905) states, 'Indeed it was by the occurrence of this plant in the Naktong flora that the present writer was able to draw the conclusion that the age is of the Mesozoic era and most probably of the Jurassic age'.

Dictyozamites and the age of the Rajmahal stage.—Of the four species reported from the Upper Gondwanas of India, two are restricted to the Rajmahal stage, namely, *D. hallii* Sahní and Rao (1936) and *D. bagjoriensis* sp. nov. The other two species *D. falcatus* (Morris) and *D. indicus* Feist. are also known from the Rajmahal stage and the East Coast Upper Gondwanas with the latter species alone represented in the Jabalpurs (Crookshank, 1936). The genus is entirely absent in the Umia stage of Cutch which is the topmost Upper Gondwanas in India. The genus, as already shown above, occurs more commonly in the Middle Jurassic elsewhere in the world with the maximum number of species represented in the Rajmahal stage. This fact may be taken as an additional evidence in support of a Middle Jurassic age for the Rajmahals as already pointed out by Seward (1917) and Sahní (1932).

Dictyozamites and the age of the coastal Upper Gondwanas.—Two species have been reported from the East Coast Upper Gondwana sediments which may possibly be somewhat younger than the Rajmahals, but not younger than the Upper Jurassic. On the evidence suggested by *D. indicus* Feist. and *D. falcatus* (Morris) and the other plant remains, it is difficult to accept Spath's (1933) suggestion that the Upper Gondwana sediments of the Madras Coast are Lower Cretaceous.

Dictyozamites and the age of the Jabalpurs and the Umias.—One species of *Dictyozamites* has been recently reported by Crookshank (1936) along with other additional forms including the larger Cycadophyte fronds, the flora on the whole now showing a greater affinity to the Rajmahals than hitherto believed. But in view of the presence of some forms in the Jabalpurs, so far reported in India only from the Umia plant beds which are known to be the topmost Upper Gondwana sediments in India, it is more satisfactory to refer the Jabalpurs to the Upper Jurassic rather than to the Middle or Lower Jurassic as suggested by Crookshank (1936).

The proposal to sub-divide the Jabalpurs into two stages namely, the lower, Chaugan containing the larger Cycadophytes with *Dictyozamites* and the 'newer conifers', and the upper, Jabalpur (Crookshank, 1936), with few Cycadophyte fronds and a fair proportion of conifers, seems unnecessary.

The absence of *Dictyozamites* from the Umia plant beds of Cutch is significant. This is in agreement with its uppermost position in the Upper Gondwanas. The beds generally referred to the Lower Cretaceous contain few representatives of the larger Cycadophyte fronds but a relatively better representation of the Coniferales.

? *Cretaceous occurrence of Dictyozamites*.—The occurrence of the genus in the Uitenhage series at Umgazana, Portoland, and in the Gamtoos valley in Cape Colony is the only doubtful report of the genus in strata younger than the Jurassic, if the lower part of the series is definitely Neocomian. Besides a brief mention in the list of Uitenhage plants (Du Toit, 1939) there seems to be no published description or illustrations of the specifically unidentified specimens for a critical review. Seward (1903a) in his account of the Uitenhage flora makes no mention of the occurrence of the genus and he concludes that the plants examined by him point to a Wealden rather than Jurassic age. Du Toit in discussing the recent evidences which have come to light, remarks that it is 'quite probable that the earliest deposits of the Uitenhage series date back into the uppermost Jurassic' (Du Toit, 1939). The presence of these fronds which, elsewhere, are known mostly from the middle division of the Jurassic, seems to lend support to the view.

VI. SUMMARY.

A new species of *Dictyozamites* (*D. bagjoriensis*) from Bagjori, Rajmahal Hills, is described and compared with the records of species so far described. The geographical and geological distribution of the genus is also discussed briefly.

VII. ACKNOWLEDGMENT.

I would like to express my sincere thanks to Mr. W. D. West, C.I.E., Director, Geological Survey of India, for his kind encouragement and for permission to publish the paper in the *Proceedings* of the National Institute of Sciences of India.

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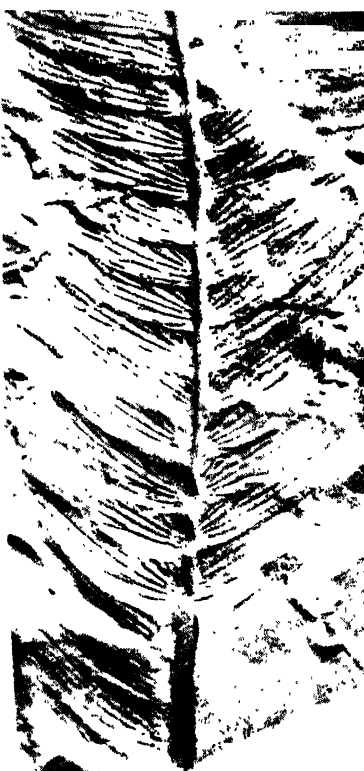
IX. EXPLANATION OF PLATE.

- FIG. 1. *Dictyozamites hallei* Sahni and Rao. Nat. size.
- FIG. 2. *Dictyozamites hallei* Sahni and Rao. \times ca. 3.
- FIG. 3. *Dictyozamites bagjoriensis* sp. nov. Nat. size.
- FIG. 4. *Dictyozamites bagjoriensis* sp. nov. \times 2.75.
- FIG. 5. *Dictyozamites bagjoriensis* sp. nov. The same frond shown in Figs. 3 and 4 further enlarged to show venation, \times 8.25.

All photographs are from untouched negatives.



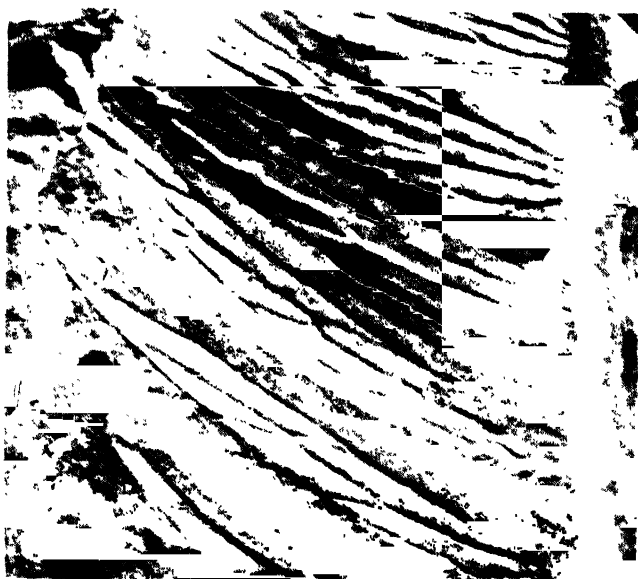
2. $\times Ca 3$



4. $\times 2.75$



3.



5. $\times 8.25$

ELECTROSTATIC FIELDS IN WHITE DWARF STARS.

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The present paper which is of a preliminary nature is concerned with the study of the rôle of electrostatic fields in determining the equilibrium configuration of a degenerate (in the sense of Fermi Dirac Statistics) stellar mass. The usual derivation of the mass-radius relation for a degenerate stellar mass tacitly implies the presence of internal electric fields. In fact as is shown below such fields severely control the size of the equilibrium configuration. However, so far as known to us, no explicit study of such fields has been undertaken (Kothari, 1944). Section 1 of the paper deals with the simplified case of a uniform density model. The treatment in this section is rather crude, but it serves to emphasise the physical basis of the arguments. The general theory is discussed in section 2.

§1. Consider a stellar mass M constituted of degenerate matter which for simplicity is assumed to contain one type of atoms only, of atomic weight A (the atomic mass being AH , where H is the mass of the H -atom) and atomic number Z (nuclear charge $+Ze$). When M is comparable to (or exceeds) the solar mass, the degenerate matter is practically completely ionised on account of pressure ionisation, and if μ denotes the mean molecular weight per free electron, we have

$$\mu = \frac{A}{Z}. \quad \dots \quad (1)$$

If we contemplate a uniform density model, then in its interior the gradient of concentration of nuclei is zero. This requires that on a nucleus the force resulting from the gravitational and electric fields must vanish—(the existence of a resultant force will imply a large concentration gradient along the direction of force).

If $u(r)$ and $v(r)$ denote respectively the gravitational and electrostatic potentials at a distance r from the centre of the configuration, and fixing the zero level of $u(r)$ and $v(r)$ by taking $u(r) = 0$, $v(r) = 0$ at $r = 0$ we have for the work $E_+(r)$ done in carrying a nucleus from $r = 0$ to r

$$E_+(r) = AHu(r) + eZv(r).$$

Hence for the uniform density model we require

$$E_+(r) = AHu(r) + eZv(r) = 0 \quad \dots \quad (2)$$

and for such a model

$$u(r) = \frac{GM(r)}{2r}, \quad \dots \quad (3)$$

where $M(r)$ is the mass enclosed within a radius r and G is the gravitational constant.

We now turn to the electrons. The work done by the gravitational and electric field in lifting an electron from the centre to a distance r is

$$E_-(r) = mu(r) - er(r),$$

* The heavier particles, i.e. the nuclei can be regarded as forming a non-degenerate gas and hence the concentration $N(r)$ of nuclei at r will strongly depend on $E_+(r)$ in accordance with Maxwell-Boltzmann distribution law. For $N(r)$ to be independent of r , we must have $E_+(r) = 0$ throughout the configuration.

where m is the mass of an electron. Using (2) we have

$$E_-(r) = mu(r) + H\mu u(r)$$

which on neglecting the first term in comparison to the second reduces to

$$E_-(r) = H\mu u(r) = \frac{H\mu GM(r)}{2r} \quad \dots \quad (4)$$

In the equilibrium case where there is no net flow of electrons across any point, the energy $E_-(r)$ must equal $\xi(0) - \xi(r)$; where ξ denotes the Gibbs free energy per electron. For a completely degenerate case ξ is

$$\xi = mc^2 \left\{ (1 + x^2)^{\frac{1}{2}} - 1 \right\} \quad \dots \quad (5)$$

where

$$x = \frac{h}{mc} \left(\frac{3n}{8\pi} \right)^{\frac{1}{3}}$$

and n is the average number of electrons per unit volume:

$$n = \frac{M}{\frac{4\pi}{3} R^3} \frac{1}{\mu H}.$$

At the surface of the configuration ξ is zero, and its value at the centre is, from (5)

$$\xi(0) = mc^2 \left[\left\{ 1 + \frac{h^2}{n^{\frac{2}{3}} c^2} \frac{1}{h^2} \left(\frac{9M}{32\pi^2 \mu H} \right)^{\frac{2}{3}} \right\}^{\frac{1}{2}} - 1 \right].$$

Hence the work done in carrying an electron from the centre of the star to its surface is simply given by $\xi(0)$. This is again equal to $E_-(r)$ (eqn. (4)). Equating these two expressions one obtains, on a little simplification

$$R = \frac{h^2}{GmH\mu} \left(\frac{9}{32\pi^2 \mu H} \right)^{\frac{1}{3}} \frac{1}{\odot^{\frac{1}{3}}} \left(\frac{\odot}{M} \right)^{\frac{1}{3}} \left\{ 1 - \frac{\mu^2 H^2 c^2}{4h^2 c^2} \left(\frac{32\pi^2 \mu H}{9} \right)^{\frac{1}{3}} M^{\frac{1}{3}} \right\}$$

where \odot stands for the mass of the sun.

To put the above relation into the standard form we substitute

$$\alpha = \left(\frac{9\pi}{4} \right)^{\frac{1}{3}}; \quad \gamma_2 = \frac{\hbar c}{GH^2};$$

$$l_0 = \frac{\hbar^2}{GmH^{\frac{1}{2}} \odot^{\frac{1}{2}}} \approx 6.18 \times 10^8 \text{ cm.} \quad \dots \quad (6)$$

and

$$M_1 = \left\{ \frac{4h^2 c^2}{\mu^2 H^2 c^2} \left(\frac{9}{32\pi^2 \mu H} \right)^{\frac{1}{3}} \right\}^{\frac{3}{2}}$$

$$= (18\pi)^{\frac{1}{2}} \frac{H\gamma_2^{\frac{3}{2}}}{\mu^2} \approx 16 \frac{\odot}{\mu^2}$$

and get

$$R = \frac{\alpha l_0}{\mu^{\frac{1}{2}}} \left(\frac{\odot}{M} \right)^{\frac{1}{3}} \left\{ 1 - \left(\frac{M}{M_1} \right)^{\frac{1}{3}} \right\}. \quad \dots \quad (7)$$

l_0 is a length characteristic of the white dwarf theory and M_1 is the Chandrasekhar-Stoner limiting mass. For M greater than M_1 the radius comes out to be negative, but for $M < M_1$, the relation is in reasonable accord with the observed mass-radius relation for the white dwarfs.

We can, following a similar procedure, work out the mass-radius relation neglecting the electric field. In this case one obtains

$$R = \frac{\alpha l_0}{\mu^{\frac{1}{3}}} \left(\frac{\mu H}{m} \right) \left(\frac{\odot}{M} \right)^{\frac{1}{3}} \left\{ 1 - \left(\frac{M}{M_1} \right)^{\frac{1}{3}} \right\} \quad \dots \quad (8)$$

where

$$M_1 = (18\pi)^{\frac{1}{3}} \frac{H\gamma_2^{\frac{2}{3}}}{\mu^{\frac{2}{3}}} \left(\frac{H\mu}{m} \right)^{\frac{2}{3}} \quad \dots \quad (8b)$$

On comparing the two sets of results obtained above one finds that the neglect of the electrical field increases the calculated radius of a white dwarf star by a factor of H/m and the limiting mass by a factor of $(H/m)^{\frac{2}{3}}$.

We also note that the total negative charge of the electrons is given by

$$Ne = e \int_0^R n \cdot 4\pi r^2 dr$$

which on using the relation

$$\frac{h^2}{2m} \left(\frac{3n}{8\pi} \right)^{\frac{2}{3}} - \frac{h^2}{2m} \left(\frac{3n_0}{8\pi} \right)^{\frac{2}{3}} = -\frac{\mu H G M(r)}{2r}$$

or

$$n = \frac{8\pi}{3} \left\{ \frac{4\pi}{3} \frac{m}{h^2} \mu H G \rho \right\}^{\frac{3}{2}} (R^2 - r^2)^{\frac{3}{2}}$$

becomes

$$Ne = \frac{\pi^2 e}{3} \left\{ \frac{m}{h^2} \mu H G M R \right\}^{\frac{3}{2}}$$

The total negative charge of the electrons is not equal to the total positive charge of the nuclei, the ratio being nearly 4×10^{-2} . This disparity between the negative and positive charges arises in our model on account of the fact that we have not incorporated Poisson's theorem for electrostatics in our derivation. To do this we proceed to the next section.

§ 2. If ξ_- and ξ_+ denote the Gibbs free energy for the electron and the ion respectively, we have

$$\begin{aligned} \frac{d\xi_-}{dr} &= -m \frac{du}{dr} + e \frac{dr}{dr}, \\ \frac{d\xi_+}{dr} &= -AH \frac{du}{dr} - \frac{Ae}{\mu} \frac{dr}{dr}, \quad \dots \quad (9) \end{aligned}$$

$$\nabla^2 u = 4\pi G \rho; \quad \nabla^2 v = -4\pi S; \quad S = A/\mu \cdot (n_+ - n_-); \quad \rho = AHn_+ + mn_-$$

where S is the charge density, n_+ the concentration of the ions and n_- that of the free electrons. From these relations one easily gets

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_+}{dr} \right) = 4\pi \{ Z e^2 (Zn_+ - n_-) - GAH(AHn_+ + mn_-) \} \quad \dots \quad (10a)$$

and

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_-}{dr} \right) = -4\pi \{ e^2 (Zn_+ - n_-) + Gm(AHn_+ + mn_-) \} \quad \dots \quad (10b)$$

To reduce the above set of equations to a single differential equation, we must introduce some supplementary condition. The existence of an electrostatic field inside a star allows us certain freedom with regard to the mass-radius relation. In the following we work out the relation under different assumptions.

Case (I). First we take

$$\frac{d\xi_+}{dr} = 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad (11)$$

so that (10a) gives

$$\frac{G\mu H}{c^2} (4Hn_+ + mn_-) = \frac{Zn_+ - n_-}{4\pi r^2}$$

or

$$\begin{aligned} Zn_+ - n_- &= n_- \cdot \frac{Z(4AmH + GA^2H^2)}{Z^2c^2 - GA^2H^2} \\ &\approx n_- \frac{G\mu^2H^2}{c^2} \approx 0 \end{aligned}$$

i.e. the total positive charge is equal to the total negative charge inside the configuration, which removes the discrepancy mentioned at the end of Section 1.

Under this assumption (10b) reduces to

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_-}{dr} \right) = -4\pi G\mu^2 H^2 n_-.$$

Substituting for ξ_- its non-relativistic value we get the standard Emden's equation of index 3/2. Its solution, in the usual way, gives

$$R = \frac{\alpha_0 l_0}{\mu^{\frac{1}{3}}} \left(\frac{\odot}{M} \right)^{\frac{1}{3}} \quad \dots \quad \dots \quad \dots \quad (12)$$

where

$$\alpha_0 = \left(\frac{9\pi^2 \omega_0^0}{128} \right)^{\frac{1}{3}} \sim 4.51,$$

which is the ordinary mass-radius relation.

Case (II). As a second case let us assume

$$Zn_+ = \alpha n_- \quad \dots \quad \dots \quad \dots \quad (13)$$

where α is some constant. The equation (10b) reduces to

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_-}{dr} \right) = -4\pi n_- \{ c^2(\alpha - 1) + Gm(\mu H \alpha + m) \}.$$

For $\alpha = 1$ we obtain (Case IIa)

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_-}{dr} \right) = -4\pi G\mu m H n_- \quad \dots \quad \dots \quad \dots \quad (14)$$

which on solving yields

$$R = \frac{\alpha_0 l_0}{\mu^{\frac{1}{3}}} \frac{\mu H}{m} \left(\frac{\odot}{M} \right)^{\frac{1}{3}} \quad \dots \quad \dots \quad \dots \quad (15)$$

i.e. in this case the calculated radius of the white dwarf star increases by a factor of $\mu H/m$.

If we take

$$\alpha = 1 + \frac{G\mu^2 H^2}{c^2}$$

(Case IIb) we find that it corresponds to the already discussed case (I), as can easily be verified.

Case (III). Let us now take

$$\frac{\xi_+}{\xi_-} = \lambda \text{ (a constant).} \quad \dots \dots \dots (16)$$

The equations (10) give

$$\frac{n_+}{n_-} = \frac{GAHm + e^2Z - Gm^2\lambda + e^2\lambda}{-GA^2H^2 + e^2Z^2 + GAHm\lambda + e^2Z\lambda}, \quad \dots \dots (17)$$

i.e., $\xi_+/\xi_- = \text{constant}$, implies $n_+/n_- = \text{const.}$

(a) Taking $Zn_+ = n_-$ as in case (IIa)

we at once get from (17)

$$\lambda = \frac{AH}{m}.$$

(b) The case $\lambda = 0$ corresponds to (I) since it can easily be shown that for this value of λ

$$\frac{Zn_+}{n_-} = 1 + \frac{G\mu^2H^2}{e^2}.$$

(c) Under the more general assumption

$$\frac{Zn_+}{n_-} = \alpha \quad \dots \dots \dots (18)$$

we have from (17)

$$\alpha = \frac{(GAHm + e^2Z)Z + \lambda Z(e^2 - Gm^2)}{(e^2Z^2 - GA^2H^2) + \lambda(GAHm + e^2Z)}. \quad \dots \dots (19)$$

By considering the first and the second differentials of α with respect to λ , one finds that α is a decreasing function of λ , and for $\lambda \rightarrow 0$

$$\alpha = 1 + \frac{GAHm}{Ze^2} + \frac{GA^2H^2}{Z^2e^2} = 1 + 0(10^{-36})$$

while for $\lambda \rightarrow \infty$

$$\alpha = 1 - \frac{GAHm}{Ze^2} - \frac{Gm^2}{e^2} = 1 - 0(10^{-40}).$$

Thus while λ varies from zero to infinite, α is practically equal to unity throughout the whole range.

Using (18) and (19) we can write (10b) as

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_-}{dr} \right) = -4\pi n_- Ge^2 \frac{(m + \mu H)^2}{\frac{\lambda}{Z} (G\mu m H + e^2) + e^2 - G\mu^2 H^2}.$$

Neglecting m in comparison with μH and $\frac{G\mu^2 H^2}{e^2}$ in comparison with unity we get

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi_-}{dr} \right) = -4\pi n_- \frac{G\mu^2 H^2}{1 + \lambda/Z}. \quad \dots \dots (20)$$

$\lambda = 0$ corresponds to case (I) whereas $\lambda = \frac{AH}{m}$ would correspond to case (IIa).

Further the radius of the star tends to infinity as $\lambda \rightarrow \infty$, since in this case we would have

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\xi}{dr} \right) = 0.$$

We observe that for the various cases discussed α is only by a term of the order of the reciprocal of Eddington Constant. Equation (13) thus ensures that the total positive charge is (almost) equal to the total negative charge.

The problem will be further examined in a subsequent paper.

Our thanks are due to Professor D. S. Kothari for suggesting the problem and for helpful discussions.

SUMMARY.

The usual derivation of the mass radius relation of a white dwarf star does not make an explicit reference to the electrostatic field. This is done in the present paper and it is shown that the electric field severely controls the properties of the equilibrium configuration.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PARTS IV AND V.

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PART IV.

Studies in the distribution and concentration of alkaline phosphatase in the testis of normal and of Desoxycorticosterone acetate treated juvenile sparrows.

INTRODUCTION.

The presence of alkaline phosphatase has been demonstrated cytochemically in the testis of some mammalian species. In the rat this enzyme occurs in both the tubules and in the intertubular tissue (Dempsey *et al.*, 1949). In the tubules the most prominent reactions occur in the spermatids and in a zone of almost hairline sharpness in the basement membrane surrounding the tubules. The nucleus of the spermatogonia and the chromosomes of the spermatocytes also exhibit moderate reactions for the phosphatase. The intertubular tissue shows the presence of variable amounts of the enzyme. Most prominent are the endothelial cells lining the blood vessels. The cellular elements in the interstitium give only a slight reaction for the phosphatase. These authors further reported that after hypophysectomy the testis of the rat becomes entirely negative for alkaline phosphatase. After replacement therapy with whole pituitary the enzyme returns to its original distribution and intensity in all the elements. Soulaire and Thibault (1948) observed that alkaline phosphatase is almost absent from the seminal tubules and the interstitial tissue of rat's testis. Wislocki (1949) demonstrated the presence of phosphatase in the seminiferous tubules and the interstitium of the testis of two species of deer, *Odocoileus virginianus borealis* and *Cervus nippon*.

Since the presence of alkaline phosphatase has not hitherto been reported in the avian testis, it seemed desirable to study the distribution and concentration of the enzyme in the testis of normal sparrows and to determine whether testicular phosphatase responded to desoxycorticosterone acetate (DCA) treatments.

EXPERIMENTAL PROCEDURE.

Juvenile Indian House Sparrows, *Passer domesticus indicus* were used in this study. Eight birds were taken for this investigation of which 4 were injected with desoxycorticosterone acetate, and the remaining 4 were left uninjected to serve as the controls. The birds were housed in cages and maintained under uniform husbandry conditions throughout the duration of the experimental period.

Desoxycorticosterone acetate in sterile sesame oil was administered intramuscularly. The daily injections (0.1 mgm.) were made into the breast muscles

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and continued for a period of 7 days. The sites of injection alternated on successive days between the right and left sides of the breast.

All the birds were autopsied on the day following the final injections. The testes were fixed immediately in chilled 80% ethyl alcohol and in alcoholic Bouin's fluid. After dehydration and imbedding in paraffin, serial sections were cut 6 microns in thickness. The tissue fixed in Bouin's fluid was stained with Ehrlich's hematoxylin. The sections of the testis fixed in ethyl alcohol were incubated in sodium glycerophosphate substrate (pH 9.5) according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. In order to allow critical observation of the granular deposits of cobalt sulfide no counterstain was used. The sections were dehydrated and mounted in the usual manner.

RESULTS.

Controls. The connective tissue forming the basement membrane of the tubules gives only a faint reaction for alkaline phosphatase. Among the other tubules elements the spermatogonial cells exhibit moderate phosphatase activity. Apart from the spermatogonia the tubules contain some scattered discrete masses of fused cytoplasm and nuclei somewhat resembling the elements of a similar nature reported in the testis of juvenile parakeets (Kar, 1949). These cellular masses probably represent a normal phase in histogenesis of the seminiferous tubules of the prepuberal testis. It is interesting to note that these masses show marked enzyme activity (Pl. IV, fig. 1). In the intertubular tissue the maximal concentration of the phosphatase is seen in the endothelium of the blood capillaries. The cellular elements of the interstitium, the fibroblasts and the interstitial cells, stain in a faint manner.

DCA Treatment.—Histologically, the tubules present a compact appearance typical of extreme immature condition of the testis. The diameter of the tubules are much smaller as compared with that of the controls and the amount of intertubular tissue is also much less. The spermatogonial cells form the principal cellular elements of the tubules and the luminal cellular mass, characteristic of the tubules of the control specimens are practically absent. In the interstitium there is a predominance of fibroblasts over the interstitial cells and the blood capillaries of this region instead of being distributed throughout the intertubular space are concentrated mainly along the corners of the seminiferous tubules. The significant finding in connection with enzymatic response is that the corticoid produces a total loss of alkaline phosphatase in the different elements of the testis, except, however, in the endothelium of the intertubular blood capillaries where great deal of enzyme activity is retained (Pl. IV, fig. 2).

DISCUSSION.

The present studies have indicated clearly that there are considerable quantities of alkaline phosphatase in the testis of juvenile sparrows. Treatment with desoxycorticosterone acetate causes marked reduction in testicular phosphatase activity.

The smaller size of the seminiferous tubules, the absence of luminal cellular mass, and the lesser amount of intertubular tissue are the significant histological features of the testis of DCA-treated sparrows which clearly indicate that the normal histogenetic progress of this organ is arrested by the corticoid. The Gomori test reveals that there is also a concomitant reduction in alkaline phosphatase activity in the testis after DCA treatment. However, the presence of testicular phosphatase in the prepuberal sparrows and its marked inhibition after DCA treatment undoubtedly suggest that this enzyme plays some unknown rôle in the progressive isogenic development of the testis.

Previous studies have shown that the activity of alkaline phosphatase may be inhibited by the action of certain chemical agents. Thus, cyanide, formaldehyde and other agents inactivate renal and intestinal alkaline phosphatase (Emmel, 1946).

Injection of androgen reduces phosphatase concentration in the avian uropygial gland (Kar, 1950a). Sex hormone treatments depress adreno-cortical phosphatase activity in the pigeon (Kar, 1950b). Administration of progesterone also results in a loss of phosphatase activity in the genital system of female pigeons (Kar, 1950c). The present investigation, therefore, adds a new instance in which the activity of enzyme is shown to be reduced after hormone treatment, and as such it provides an interesting evidence to the thesis that the hormones exert their effects on organs by regulating the rate of enzyme activities.

SUMMARY.

Alkaline phosphatase is demonstrable in the seminiferous tubules and in the endothelium of the intertubular blood vessel of the testis of juvenile sparrows. DCA treatment causes a marked loss of phosphatase activity from the component parts of the testis with the exception of endothelium of the intertubular blood capillaries. The possible significance of this enzymatic inhibition is discussed.

PART V.

Responses of the adreno-cortical alkaline phosphatase in the pigeon to Progesterone and Desoxycorticosterone acetate.

INTRODUCTION.

Dempsey *et al.* (1949) observed that alkaline phosphatase disappears from the fasciculata and the reticularis of the rat's adrenal cortex after hypophysectomy but persists in the zona glomerulosa. Replacement therapy with whole pituitary powder causes a reappearance of the enzyme and a return to a condition approximating that of the normal gland. Elftman (1947) reported that the phosphatase is absent from the adrenal cortex of the castrated male, the ovariectomized female, and the immature male mice. Treatment of such animals with androgen results in the reappearance of the cortical phosphatase. Kar (1950b) studied the distribution and concentration of alkaline phosphatase in the adrenal cortex of the pigeon and further noted that treatment with androgen or estrogen reduced cortical phosphatase activity.

The present report relates to a study of the effects of progesterone and desoxycorticosterone acetate (DCA) on the distribution and concentration of alkaline phosphatase in the adrenal cortex of the pigeon.

EXPERIMENTAL.

Female pigeons, 110 days old were used in this study. Fifteen birds were taken for this investigation of which 5 birds each were injected with progesterone and DCA and the remaining 5 were left uninjected, to serve as the controls. The birds were all housed in cages under uniform husbandry conditions throughout the duration of the experimental period.

Progesterone or DCA in sesame oil was administered intramuscularly. The daily injections (0.1 mg.) were made into the breast muscles and continued for a period of 24 days. The sites of injection alternated on successive days between the right and left sides of the breast.

Autopsy followed 24 hours after the final injections. The adrenals were fixed immediately in chilled 80% ethyl alcohol and in 10% formol-saline. After dehydration and imbedding in paraffin, serial sections were cut 6 microns in thickness. The tissue fixed in formol-saline was stained with Mallory's trichrome stain. The phosphatase activity was studied by the technique of Gomori (1941) described in Part IV of this series.

RESULTS.

Controls. In the adrenal of the untreated pigeons the phosphatase is present in the capsular cells. Moderate amounts of the enzyme are also present in the endothelium of the capsular blood vessels. In the cells of the peripheral cortical strands the phosphatase is visible in the nucleus but not in the cytoplasm. Enzymatic reaction, however, is uniform in the cells of the cortical strands located in the central region of the gland. The endothelium of the capillary network in the gland also shows strong phosphatase activity (Pl. IV, fig. 3).

Progesterone treatment. The amount of phosphatase is somewhat reduced in the adrenal capsule of the progesterone recipients. The endothelium of the blood vessels in the capsule, however, continues to give a positive reaction for the enzyme. In the peripheral cortical strands moderate amounts of phosphatase are present while in those of the central region of the gland intense enzyme activity is visible. The endothelium of the blood capillaries in the gland also gives strong positive reaction for the phosphatase (Pl. IV, fig. 4).

DCA Treatment.—The capsule of the adrenal gland in the DCA-treated pigeons shows intense phosphatase activity. However, the amount of enzyme in the endothelium of the capsular blood vessels is extremely small. In the peripheral cortical strands very strong nuclear phosphatase activity is visible while the cytoplasmic enzyme concentration appears to be little. There is, however, a pronounced mobilization of the phosphatase in the strands of the central region of the gland. The component cells of these strands are totally masked by black granular deposits of cobalt sulfide. Even the contour of these cells is made invisible by these black deposits (Pl. IV, fig. 5). The endothelium of the capillary network also gives intense reactions for the enzyme.

DISCUSSION.

The results secured in the experiment demonstrate clearly that the phosphatase activity is markedly increased in the adrenal cortex of the pigeon after progesterone or DCA treatments, the effect of the latter being more marked.

It has been reported (Kar, 1950b) that only negligible quantities of alkaline phosphatase are present in the peripheral adreno-cortical strands of the pigeon; in the more centrally located strands, however, the concentration of the enzyme is found to be considerably high. Treatment with androgen or estrogen do not neutralize this difference in the amount of phosphatase between the cortical strands in the two regions of the gland. In the present study it is seen that the hormonal treatments are similarly ineffective in neutralizing the difference in cortical phosphatase activity in the two regions of the gland. In view of the known histogenesis of the adreno-cortical cells in the pigeon (Miller and Riddle, 1942), the present findings corroborate the view that in this species the phosphatase activity is correlated with the age of the cortical cells (Kar, 1950b). Thus, the amount of the enzyme is very little in the young cortical cells in the periphery, but reaches a considerably higher concentration in the older cells located in the central region of the gland.

Recent studies have shown that the activity of the phosphatase may be enhanced by the injection of hormones. Thus, estrogen treatment causes an increase in uterine phosphatase in the mice (Atkinson and Elftman, 1947). Phosphatase activity is also markedly increased in the vaginal epithelium of the ovariectomized mice following estrogen therapy (Kammell and Atkinson, 1948). Androgen treatment causes a significant mobilization of alkaline phosphatase in the ovarian theca of the pigeon (Kar, 1950a). Comparable results are also obtained in the ovary of the same species after desoxycorticosterone acetate treatment (Kar, 1950a). The present report, therefore, adds a new example of augmentation of phosphatase activity by hormones. It is interesting to note that both progesterone and DCA are effective in enhancing the cortical phosphatase activity. However, this cyto-

chemical similarity between the two hormones is to be expected since their chemical structure and physiological actions are great deal alike (*vide* Burrows, 1947).

SUMMARY.

Intramuscular injection of progesterone increases the concentration of alkaline phosphatase in the adrenal cortex of the pigeon. Desoxycorticosterone acetate causes a similar but more pronounced augmentation of adreno-cortical phosphatase activity in the same species. The significance of this cytochemical similarity between the two hormones is pointed out and discussed.

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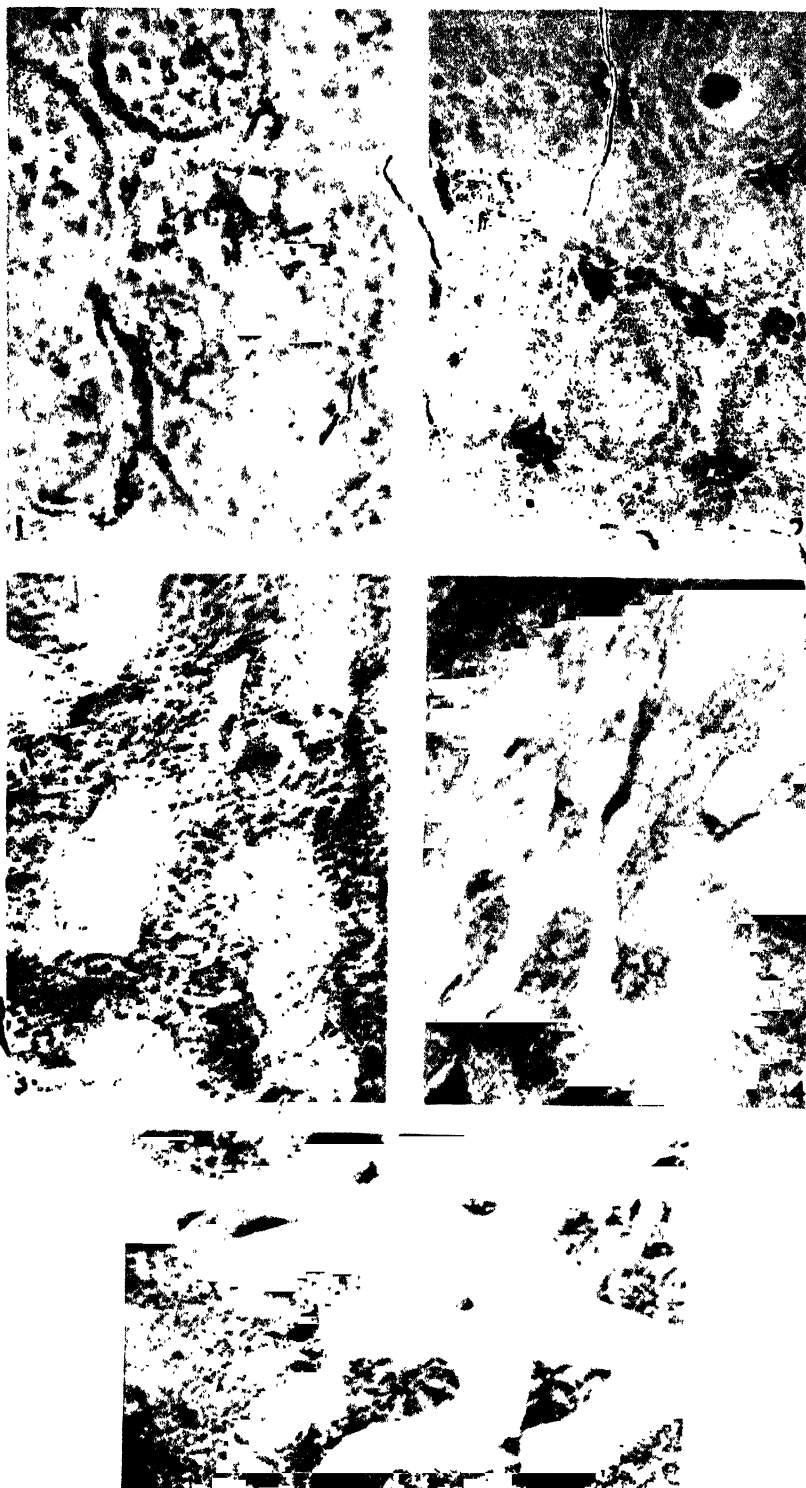
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EXPLANATION OF PLATE.

(All figures are photomicrographs and are magnified $\times 130$.)

- FIG. 1. Section through the testis of an untreated juvenile sparrow. Note the distribution of alkaline phosphatase.
- FIG. 2. Section through the testis of a DCA-treated sparrow. Note the presence of the enzyme in the endothelium of the intertubular blood capillaries.
- FIG. 3. Section through the adrenal cortex of an untreated pigeon. Note the distribution of alkaline phosphatase.
- FIG. 4. Section through the adrenal cortex of a progesterone-treated pigeon. Note the increase in enzyme activity.
- FIG. 5. Section through the adrenal cortex of a DCA-treated pigeon. Compare with figs. 3 and 4.



ON A TREATMENT OF IMPERFECT GAS AFTER FERMI'S MODEL (III).

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INTRODUCTION.

In two previous papers (Dutta I and II, 1947), the behaviour of the imperfect gas has been investigated by a new method. In the first of the above papers, the equation of state of an imperfect gas has been deduced in two stages in a very simple manner. In the first stage, the effect of finite dimension of molecules has been taken into account by a method similar to that of Fermi in Fermi-Dirac Statistics, and essentially amounting to a specialisation of the Pauli-Fermi principle of Exclusion. In the second stage, the correction for cohesive forces has been taken into account by introducing the idea of the effective volume slightly greater than the actual volume of the enclosure.

In considering the effect of finite dimension, in that paper, the distribution of molecules in the physical space, and that of their representative points in the momenta space have been considered separately. In distributing molecules in the physical space, this space has been divided into cells of dimension, b , equal to the rigid volume of exclusion of each molecule, and, then, the effect of this exclusion in the physical space due to finite dimension of rigid molecules has been expressed in the form of a principle of exclusion, quite similar to that of Pauli-Fermi in Fermi-Dirac Statistics. This principle has been formulated thus: 'No cell of the physical space can be occupied by more than one molecule at the same instant'. Then, the momenta space has been divided into cells of volume h^3/b , and, distribution of the representative points in this space has been considered in the usual way. The Pauli-Fermi principle is effectively implemented in this manner.

In the second paper, the effect of finite dimension of molecules, and, that of cohesion amongst the molecules have been considered in a single step in a simple and straight way. For this, over and above the division into cells of small volume, the physical space is divided into two layers, the interior, and, the surface layer, corresponding to different potential energies.

In the present paper, the behaviour of the assembly of molecules of finite dimension under any field of force has been investigated. Of course, there is a simple restriction, on the nature of field of force, namely the gradient of the field is so small that any change in the magnitude of the field within a length of molecular dimension may be ignored. Evidently this does not materially affect the range of application of the results obtained, since, in the case of an actual physical assembly, the gradient of the field may be assumed to have this characteristic. Here, the physical space, in addition to the division into cells of volume b , is divided into potential energy layers, just as, in Fermi-Dirac Statistics, the phase-space is divided into energy layers. Then, as in the previous paper, the distribution in the physical space and that in the momenta space have been considered separately. The thermodynamic probability for distribution in the physical space has been calculated after Fermi, and that for the momenta space in the usual classical way; the product of these two gives the total thermodynamic probability.

DESCRIPTION OF THE ASSEMBLY.

The assembly under consideration consists of N non-dissociating and non-associating molecules, each commanding equal rigid volume of exclusion of magnitude b . The assembly is enclosed within a volume V .

For considering the distribution in the physical space, as stated above, the total volume in the physical space is divided into potential-energy layers of volumes $V_1, V_2, \dots, V_m, \dots$, corresponding to potential energies, $w_1, w_2, \dots, w_m, \dots$ respectively. Let, at any instant, $N_1, N_2, \dots, N_m, \dots$ be the number of molecules in layers of volume $V_1, V_2, \dots, V_m, \dots$ respectively. Each layer is, then, divided into cells of volume b as usual. It is also assumed that $b \ll V_1, V_2, \dots, V_m, \dots$. Let a_i represent the number of molecules with kinetic energy ϵ_i .

CALCULATIONS.

The thermodynamic probability, calculated as in previous papers, becomes,

$$W = \frac{N!}{\prod_m N_m! \left(\frac{V_m}{b} - N_m\right)!} \cdot \frac{N!}{\prod_i a_i!}.$$

Then, by the use of Stirling's formula for approximation of factorials, this can be written as,

$$\log W = \left[\sum_m \left\{ \left(\frac{V_m}{b}\right) \log \left(\frac{V_m}{b}\right) - \left(\frac{V_m}{b} - N_m\right) \log \left(\frac{V_m}{b} - N_m\right) - N_m \log N_m \right\} + N \log N - \sum_i a_i \log a_i \right]. \quad (1)$$

To get the entropy for the assembly in thermodynamic equilibrium, this is to be maximised subject to the following conditions:-

$$\left. \begin{aligned} \sum_i a_i &= N, \\ \sum_m N_m &= N, \\ \sum_i a_i \epsilon_i + \sum_m N_m w_m &= E. \end{aligned} \right\} \quad \dots \quad (2)$$

where N , E , and V_m 's remain constant.

The variation of expression (1) after the use of Lagrange's undetermined multipliers gives

$$a_i = e^{-\lambda - \mu \epsilon_i} \quad (\text{for all } i\text{'s}) \quad \dots \quad (3)$$

$$\frac{V_m}{N_m b} - 1 = e^{\nu + \mu w_m} \quad (\text{for all } m\text{'s}) \quad \dots \quad (4)$$

where λ , μ , ν are undetermined multipliers.

Then,

$$N_m = \frac{V_m}{b} \cdot \frac{1}{e^{\nu + \mu w_m} + 1} \quad (\text{for all } m\text{'s}) \quad \dots \quad (5)$$

Then, by Boltzmann's hypothesis, and from above equations, we have,

$$S = k \left[N(\lambda + \nu) + \mu N + N \log N + \sum_m \frac{V_m}{b} \log (1 + e^{-\nu - \mu w_m}) \right]$$

By the well-known thermodynamic relation we have,

$$\frac{1}{T} = \left(\frac{\partial S}{\partial E} \right)_\nu = k\mu, \text{ or, } \mu = \frac{1}{kT}, \quad \dots \dots \dots (6)$$

Again, as is shown in the paper (1, Dutta, 1947),

$$N = \sum_i a_i = e^{-\lambda} \sum_i e^{-\epsilon_i/kT}$$

or

$$e^\lambda = \frac{1}{N} \sum_i e^{-\epsilon_i/kT} \dots \dots \dots (7)$$

$$= \frac{1}{N} \iiint e^{-\epsilon/kT} \frac{dp_x dp_y dp_z}{h^3/b} \dots \dots \dots$$

or

$$\lambda = \log \left\{ \frac{1}{N} \cdot \frac{b}{h^3} (2\pi mkT)^{\frac{3}{2}} \right\} \dots \dots \dots (8)$$

From (2)

$$N = \sum_m N_m = \sum_m \frac{V_m}{b} \frac{1}{1 + e^{\nu + \frac{w_m}{kT}}} \dots \dots \dots (9)$$

$$= \frac{1}{b} \int_\nu \frac{dV}{1 + e^{\nu + w/kT}} \dots \dots \dots (10)$$

where the element of volume dV is the volume of layers of potential energy w . This is the equation for determining ν .

Then,

$$S = Nk \left[\frac{3}{2} \log T + \log \left\{ \frac{b}{h^3} (2\pi mk)^{\frac{3}{2}} \right\} + \nu + \frac{E}{NkT} + \sum_m \frac{V_m}{Nb} \log \left(1 + e^{-\nu - \frac{w_m}{kT}} \right) \right] \dots \dots \dots (11)$$

and

$$\Psi = Nk \left[\frac{3}{2} \log T + \log \left\{ \frac{b}{h^3} (2\pi mk)^{\frac{3}{2}} \right\} + \nu + \sum_m \frac{V_m}{Nb} \log \left(1 + e^{-\nu - \frac{w_m}{kT}} \right) \right] \dots \dots \dots (12)$$

Now, in gaseous phase $\frac{V_m}{Nb} \gg 1$ for all m 's.

$$\therefore \frac{V_m}{Nb} = e^{\nu + \frac{w_m}{kT}}, \text{ or } N_m = \frac{V_m}{b} e^{-\nu - \frac{w_m}{kT}}. \dots \dots \dots (13)$$

This is the well-known Boltzmann law for distribution in a field for gases.

Now, by (2)

$$\begin{aligned} N &= \sum N_m = \sum \frac{V_m}{b} e^{-\nu - \frac{w_m}{kT}} \\ &= \frac{1}{b} e^{-\nu} \int_V e^{-\frac{w}{kT}} dV \quad \dots \quad \dots \quad \dots \quad (14) \end{aligned}$$

or

$$\begin{aligned} e^{-\nu} &= \frac{1}{Nb} \sum_m \frac{V_m}{b} e^{-\frac{w_m}{kT}} \\ &= \frac{1}{Nb} \int_V e^{-\frac{w}{kT}} dV \quad \dots \quad \dots \quad \dots \quad (15) \end{aligned}$$

Thus, ν has a meaning similar to Ψ_q of Gibbs (Gibbs, 1926).

Now, the total potential energy of the assembly

$$= \sum_m N_m w_m = \frac{e^{-\nu}}{b} \sum_m e^{-\frac{w_m}{kT}} V_m = NkT^2 \frac{\partial}{\partial T} \left\{ \log \left(\sum_m \frac{V_m}{Nb} e^{-\frac{w_m}{kT}} \right) \right\} \dots (16)$$

$$= T^2 \frac{\partial(Nk\nu)}{\partial T} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$

Similarly, the total kinetic energy

$$= \sum_i a_i \epsilon_i = NkT^2 \frac{\partial}{\partial T} \left(\log \sum_i e^{-\epsilon_i/kT} \right) \quad \dots \quad \dots \quad \dots \quad \dots \quad (18)$$

$$= T^2 \frac{\partial}{\partial T} (Nk\lambda) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (19)$$

$$= \frac{3}{2} NkT.$$

Therefore the total energy

$$\begin{aligned} &= T^2 \frac{\partial(Nk\lambda)}{\partial T} + T^2 \frac{\partial(Nk\nu)}{\partial T} \\ &= T^2 \frac{\partial}{\partial T} \left\{ Nk(\lambda + \nu) \right\} = T^2 \frac{\partial}{\partial T} \left\{ Nk \log \left(e^{\lambda + \nu} \right) \right\} \\ &= T^2 \frac{\partial}{\partial T} \left\{ Nk \log (e^{\lambda} \cdot e^{\nu}) \right\} = T^2 \frac{\partial}{\partial T} \left\{ Nk \log \left(\sum_i e^{-\frac{\epsilon_i}{kT}} \sum_m V_m e^{-\frac{w_m}{kT}} \right) \right\} \\ &= T^2 \frac{\partial}{\partial T} \left\{ Nk \log \left(\sum_{i,m} V_m e^{-\frac{\epsilon_i + w_m}{kT}} \right) \right\} \quad \dots \quad \dots \quad \dots \quad \dots \quad (20) \end{aligned}$$

This is the usual relation between the energy and the 'sum-over-states' (Zustands-summe) of Planck. Now, here, it is to be noted that the sum-over states can be decomposed into two parts, one connected with the configurational space, and, the other with the momenta space. This is consistent with the idea of splitting the

phase-space into the configurational space and the momenta-space as is done in our method.

Now

$$\Psi = Nk \left[\frac{3}{2} \log T + \log \left\{ \frac{b}{h^3} (2\pi mk)^{\frac{3}{2}} \right\} + \log \left\{ \frac{1}{Nb} \sum_m V_m e^{-\frac{w_m}{kT}} \right\} + \frac{1}{N} \sum_m \frac{V_m}{b} \left(1 + e^{-\nu - \frac{w_m}{kT}} \right) \right].$$

Since for gas,

$$e^{-\nu - \frac{w_m}{kT}} = \frac{N_m b}{V_m} \ll 1.$$

$$\begin{aligned} \therefore \frac{1}{N} \sum_m \frac{V_m}{b} \log \left(1 + e^{-\nu - \frac{w_m}{kT}} \right) &= \frac{1}{N} \left[\sum_m \frac{V_m}{b} e^{-\nu - \frac{w_m}{kT}} + \frac{1}{2} \sum_m \frac{V_m}{b} e^{-2\nu - \frac{2w_m}{kT}} \right] \\ &= 1 + \frac{1}{2} \cdot \frac{1}{N} e^{-2\nu} \sum_m \frac{V_m}{b} e^{-2\frac{w_m}{kT}} \quad (\text{approximately}) \\ &= 1 + \frac{Nb}{2} \frac{\int_V e^{-\frac{2w}{kT}} dV}{\left[\int_V e^{-\frac{w}{kT}} dV \right]^2} \quad \dots \dots \dots (21) \end{aligned}$$

$$\therefore \Psi = Nk \left[\frac{3}{2} \log T + \log \left\{ \frac{b}{h^3} (2\pi mk)^{\frac{3}{2}} \right\} + \log \left\{ \frac{1}{Nb} \int_V e^{-\frac{w}{kT}} dV \right\} + 1 + \frac{Nb}{2} \frac{\int_V e^{-\frac{2w}{kT}} dV}{\left\{ \int_V e^{-\frac{w}{kT}} dV \right\}^2} \right] \quad \dots (22)$$

Then, by the well-known thermodynamic relation,

$$p = T \left(\frac{\partial \Psi}{\partial V} \right)_T$$

we have,

$$\begin{aligned} p = NkT \left[\frac{e^{-\frac{w_B}{kT}}}{\int_V e^{-\frac{w}{kT}} dV} + \frac{Nb}{2} \frac{e^{-\frac{2w_B}{kT}} \left\{ \int_V e^{-\frac{w}{kT}} dV \right\}^2 - 2 \left\{ \int_V e^{-\frac{2w}{kT}} dV \right\} \left\{ \int_V e^{-\frac{w}{kT}} dV \right\} e^{-\frac{w_B}{kT}}}{\left\{ \int_V e^{-\frac{w}{kT}} dV \right\}^3} \right] \end{aligned}$$

$$= \frac{NkT'}{\int_V e^{-\frac{w}{kT'}} dV} e^{-\frac{w_B}{kT'}} \left[1 + \frac{1}{2} \frac{Nb}{\int_V e^{-\frac{w}{kT'}} dV} \left\{ e^{-\frac{w_B}{kT'}} - \frac{2 \int_V e^{-\frac{2w}{kT'}} dV}{\int_V e^{-\frac{w}{kT'}} dV} \right\} \right]$$

where w_B is the potential energy in boundary region.

Let us define an effective volume as follows:

$$V' = \int_V e^{-\frac{w}{kT'}} dV = V + \int_V \left(e^{-\frac{w}{kT'}} - 1 \right) dV \quad \dots \quad (23)$$

$$= V + a$$

where

$$a = \int_V \left(e^{-\frac{w}{kT'}} - 1 \right) dV \quad \dots \quad (24)$$

Then, the expression for pressure can be obtained as,

$$p = \frac{NkT'}{V'} e^{-\frac{w_B}{kT'}} \left[1 + \frac{\beta'}{V'} \right]$$

$$= \frac{NkT'}{V' - \beta'} e^{-\frac{w_B}{kT'}} \quad \dots \quad (25)$$

where

$$\beta' = \frac{1}{2} Nb \left\{ e^{-\frac{w_B}{kT'}} - 2 \frac{\int_V e^{-\frac{2w}{kT'}} dV}{\int_V e^{-\frac{w}{kT'}} dV} \right\} \quad \dots \quad (26)$$

This is in the form of Dieterici's Equation of state.

The usual Dieterici's Equation of state of the first type is

$$p = \frac{NkT'}{V - \beta} e^{-\frac{\alpha}{NkTV}} \quad \dots \quad (27)$$

where the quantities α , β are proportional to N^2 and N respectively.

Now, to deduce an equation of state (25) in complete agreement with that of Dieterici given by the equation (27), we have to remember that w_B is as usual proportional to N/V . If we write,

$$\frac{w_B}{kT} = \frac{\alpha}{NkTV} \quad \dots \quad (28)$$

then, obviously,

$$\alpha \propto N^2 \quad \dots \quad (29)$$

Now, in the case of an external force, or, in the case of molecular interaction, weak compared to KT , we have,

$$a = \int_V \left(e^{-\frac{w}{kT}} - 1 \right) dV \cong - \int \frac{w}{kT} dV \quad (\text{approximately})$$

$$\therefore a \propto N \quad \dots \quad \dots \quad \dots \quad \dots \quad (30)$$

From the equation (26)

$$\beta' \propto N \quad \dots \quad \dots \quad \dots \quad \dots \quad (31)$$

Again, if we write

$$\beta = \beta' - a \quad \dots \quad \dots \quad \dots \quad \dots \quad (32)$$

then,

$$\beta \propto N \quad \dots \quad \dots \quad \dots \quad \dots \quad (33)$$

Then, the equation can be written as

$$p(V - \beta) = NkT e^{-\frac{\alpha}{NkT^s V}} \quad \dots \quad \dots \quad \dots \quad (34)$$

This is identical with the equation (27).

Now the equations, (26), (30), (31), (32), show that α , β depend on temperature. Now, for successful application of Dieterici's equation over a wide range of temperature and pressure, α , β are generally taken as function of temperature. It is also to be noted that in the general form of Dieterici's equation of state,

$$p(V - \beta) = NkT e^{-\frac{\alpha}{NkT^s V}} \quad \dots \quad \dots \quad \dots \quad (35)$$

Thus, according to Dieterici, α of equation (34) must in general vary as $1/T^{s-1}$. In Reinganum's treatment of imperfect gases, the volume correction has been obtained as a function of temperature in the form as obtained here.

Now, another important point should not be passed over unnoticed. In equation (25), the effective volume defined in (23) plays the rôle of volume. This shows that the volume correction to be introduced in the thermodynamic expressions has two parts, one due to finite dimension of volume, and the other due to the field of force.

Now, in case of a field of negative potential energy as in the case of cohesion or intermolecular attraction, w being negative, a , defined in (24) is positive, so V' is greater than V . The concept of effective volume V' being greater than V and playing the rôle of V , has also been introduced already in a previous paper (I, Dutta, 1947) from other physical considerations.

Now, we want to see whether our theory is sufficient to explain other macroscopic phenomena of nature outside the domain of thermodynamics. For simplicity, we shall attempt here to deduce the law of pressure of hydrostatics. Now, in order to extend our investigation to problems of hydrostatics, it is to be remembered that the fundamental criteria of fluid at rest is that every portion of fluid is at rest and, so, hydrostatics is based on the concept of local thermodynamic equilibrium. Also, in hydrostatics, the pressure is a point function, i.e., to every level an idea of the pressure of the level can be attached.

Now, for any level, we have

$$\log \left(\frac{V_m}{N_m b} - 1 \right) = \nu + \frac{w_m}{kT} \quad \dots \quad \dots \quad (36)$$

where ν is same for all levels.

Omitting the suffixes for different layers, we can write,

$$\log \left(\frac{v}{nb} - 1 \right) = v + \frac{w}{kT}$$

where n is the number of molecules in a volume v in the layer having a potential w .

Then, differentiating with respect to any one of co-ordinates, we have

$$-\frac{1}{\frac{v}{nb} - 1} \cdot \frac{v}{nb} \cdot \frac{1}{n} \cdot \frac{\partial n}{\partial x} = \frac{1}{kT} \frac{\partial w}{\partial x}, \quad \dots \quad (37)$$

Now, according to the concept of local thermodynamic equilibrium for every layer, the pressure at a level of constant potential (I, Dutta, 1947), is

$$\begin{aligned} p &= -\frac{kT}{b} \log \left(1 - \frac{nb}{v} \right) \\ \therefore \frac{\partial p}{\partial x} &= \frac{kT}{b} \cdot \frac{1}{1 - \frac{nb}{v}} \cdot \frac{b}{v} \cdot \frac{\partial n}{\partial x} \\ &= kT \cdot \frac{1}{\frac{nb}{v} - 1} \cdot \frac{v}{nb} \cdot \left(-\frac{1}{n} \right) \frac{\partial n}{\partial x} \cdot \frac{n}{v} \\ &= -\frac{n}{v} \frac{\partial w}{\partial x} \end{aligned}$$

or

$$\frac{1}{n} \frac{\partial p}{\partial x} = -\frac{\partial w}{\partial x} \quad \dots \quad (38)$$

and similarly for other co-ordinates.

This is the well-known equation of hydrostatic equilibrium.

It should be noted here that the thermodynamic pressure obtained from Ψ as in (25) is different from the hydrostatic pressure, when there is a field of force. The pressure obtained by differentiating Ψ may be looked upon as a thermodynamic parameter connected with work done during expansion.

SOME IMPORTANT GENERAL REMARKS

It should be noted that identical results are obtained from the thermodynamic functions, or for distributions in the physical and the momenta spaces, if the total thermodynamic probability for the entire assembly is written as the product of thermodynamic probabilities of all layers considered separately. According to this idea, the thermodynamic probability is,

$$W = \prod_m W_m = \prod_m \frac{\left(\frac{V_m}{b} \right)!}{\left(\frac{V_m}{b} - a_m \right)! \prod_i u_{mi}!} \quad \dots \quad (39)$$

where V_m 's, N_m 's, b have the same meaning as in the previous case, and a_{mi} is the number of molecules in the m th layer, (i.e., of potential energy w_m) and, of kinetic energy, ϵ_i .

The restricting conditions, here, are :

$$\left. \begin{aligned} \sum_l a_{ml} &= N_m \\ \sum_m a_{ml} &= a_l \\ \sum_m N_m &= \sum_{ml} a_{ml} = N \\ \sum_{ml} a_{ml} (w_m + \epsilon_l) &= E \end{aligned} \right\} \dots \dots \dots (40)$$

where, in the present variation, N , E and V_m 's remain constants.

All expressions for a_{ml} 's, N_m 's, a_l , Ψ , p , S are same as those obtained above.

Now, an objection may be raised against the present method that there is no *a priori* reason for a permanency of distributions of molecules in the physical space, and of representative points in momenta space. It has to be remembered that the permanency of distributions in the phase space is supported by the Liouville's theorem, which suggests that there is no tendency of clustering in the phase space. Now no theorem similar to that of Liouville can be established for the physical space or the momenta space separately. So, in order to establish permanency of distributions, considered here, it is necessary to show that the entire discussion can be fitted, quite well, into the usual formalism of representation of complexions in the phase-space, and, so, there is some permanency of distributions in the phase-space.

If we start with the representations of the complexion in the phase space, then, the division of configurational space into cells of dimension 'b' in our formalism is equivalent to the division of the phase space into cylinders of which the dimensional cross-section corresponding to the configurational co-ordinates is equal to b. Then, the principle of exclusion denoting the effect of finite dimension of molecules states that more than one representative point cannot come within one such single cylinder.

Division of physical space into the potential energy layers is equivalent to the grouping of these cylinders into different classes. Now, these cylinders are again divided into kinetic energy layers (or better into kinetic-energy racks). The number of cylinders corresponding to the potential energy w_m is V_m/b . Let a_{ml} be the number of representative points of molecules having a potential energy W_m , and a kinetic energy ϵ_l at an instant. Then, at the instant, a_{ml} of the V_m/b cylinders are occupied at the l th rack, each occupied by only one.

Then, the number of different ways, in which, of V_m/b cylinders, a_{m1} are occupied by representative points, only one in each, in the kinetic energy rack ϵ_1 is

$$\frac{\left(\frac{V_m}{b}\right)!}{a_{m1}! \left(\frac{V_m}{b} - a_{m1}\right)!}$$

Due to the exclusion principle, no other energy layer of any of these a_{m1} cylinders can be further occupied by any other second representative point. Then, the number of ways in which a_{m2} cylinders are occupied by representative points, only one point in each cylinder in rack of kinetic energy ϵ_2 , is given by,

$$\frac{\left(\frac{V_m}{b} - a_{m1}\right)!}{a_{m2}! \left(\frac{V_m}{b} - a_{m1} - a_{m2}\right)!}$$

and so on. Finally, the required number of ways, in which, of V_m/b cylinders, a_{m1} are occupied in ϵ_1 rack, a_{m2} in ϵ_2 rack, and so on, is

$$\frac{\left(\frac{V_m}{b}\right)!}{a_{m1}! \left(\frac{V_m}{b} - a_{m1}\right)!} \cdot \frac{\left(\frac{V_m}{b} - a_{m1}\right)!}{a_{m2}! \left(\frac{V_m}{b} - a_{m1} + a_{m2}\right)!} \cdots \frac{\left(\frac{V_m}{b} - a_{m1} + \dots + a_{mn} - 1\right)!}{a_{mn}! \left(\frac{V_m}{b} - a_{m1} + \dots + a_{mn}\right)!} = \frac{\left(\frac{V_m}{b}\right)!}{\left(\frac{V_m}{b} - N_m\right)! \prod_i a_{mi}!}$$

Total thermodynamic probability for all classes of cylinders

$$= \prod_m \frac{\left(\frac{V_m}{b}\right)!}{\left(\frac{V_m}{b} - N_m\right)! \prod_i a_{mi}!}$$

This is the expression (39) for W . The restricting conditions are the same as in (40). So, the rest of the treatment is identical.

The principle of exclusion, used here, may be looked upon as equivalent to the Pauli-Fermi principle of exclusion in the phase-space, but applied in a special way to take an account of finite size of the particles. The Pauli-Fermi principle, in its general formulation, implies that exclusion of more than one particle from an elementary 6-dimensional position-momenta cell of extension h^3 , but of no prescribed shape. Now, so long as the particles, under considerations are negligibly small in size, e.g., electrons, there is no difficulty of application but, the exclusion, as actually applied, is in the momenta-space only. In actual working of Fermi-Dirac statistics, the integral over configurational co-ordinates is replaced by the total volume. This is practically equivalent to the ignoring of the finite size of particles. If the particles of finite size are considered, then, a large number of restrictions amongst the configurational co-ordinates in form of several inequalities appears in the calculations due to the size of the particles. The problem, thus, becomes intractable, without special simplifying approximations. Here, as a first approximation, we have divided the configurational space into elementary cells of dimension of same size, in which we postulate that more than one particle cannot exist. For statistical calculations, we replace material particles by points, and, apply the principle of exclusion in the configurational space. This gives a fairly good approximation as shown by results arrived here and elsewhere (Dutta, 1947, 1948).

An important note

Here, it is to be admitted that division of the configurational space into layers of potential energies $w_1, w_2, \dots, w_m, \dots$ is subject to same theoretical objections, as the potential energies $w_1, w_2, \dots, w_m, \dots$ may depend on the instantaneous distributions of particles. In case of external field only, or, in case of an external field and a field of molecular interaction, weak compared to the external field, the division of the configurational space into potential energy layers is evidently quite permissible. But, in case of other fields mainly due to the interaction amongst the molecules themselves, the validity of division of the configurational space into potential energy layers is not above all criticism. In support of the procedure, used above, it can be added that the similar ideas of existence of same (average) constant

energies, w_1, w_2, \dots ab-initio is common amongst other similar statistical theories of imperfect gases, specially in presence of long-range forces (Fowler, 1936).

CONCLUSION

Here it is found that the present method is suitable for the taking into account of the effects of finite dimension of molecules and of any field of force, of which the gradient is very small compared to the length of molecular dimension. It is also found that similar discussions can be done yielding the above results if one sticks to the representation of states in phase-space. But the method, used here, by considering the physical space and momenta space separately, simplifies the entire discussion.

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SUMMARY

In this paper, the statistical theory of imperfect gases, already developed in two previous papers by the application of a principle of exclusion, a special form of that of Pauli-Fermi, and, of method of Fermi, has been extended to the case of general field of forces. The equation of state, yielding Dieterici's equation upto first approximation, has been obtained by taking into account a general type of field of force, and the finite size of particles. This has been done by dividing the configurational space into different potential layers and also into cells of volume equal to the finite volume of the particles, as is done in the discussion of Fermi-Dirac Statistics. Here, as in the previous papers, the distributions for the configuration-space and, for the momenta-space have been considered separately. At the end of this paper, it has been shown that some discussions hold good, and the same results can be obtained without splitting up phase-space into configuration space and momenta-space.

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STUDIES ON ANTI-THIAMINE FACTOR IN MUSTARD (*BRASSICA JUNCEA*).

PART I.—ISOLATION AND KINETICS.

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INTRODUCTION.

It is now clearly recognized that both animal and plant materials contain substances which antagonize the action of thiamine. According to Hart *et al.* (1911), a ration containing mainly of wheat products was inadequate for the maintenance of heifers and swine. In subsequent papers (1914, 1916), they described the pathological conditions, manifested by swine on a diet rich in wheat products, which are analogous to, if not identical with, the pathological conditions recorded for polyneuritis in fowls. This, they considered to be due to the presence of some toxic principle in the wheat products.

McCollum *et al.* (1916) reported the occurrence of a substance, which is distinctly toxic to animals, in wheat germ. This could be extracted to a great extent with ether. Moore (1914) described a condition in swine, closely resembling 'beriberi' when fed on 'rice meal'. These findings were later verified and confirmed by Williams (1926).

Recently Weswig *et al.* (1946), Fabriani *et al.* (1948), Thomas *et al.* (1949) reported the occurrence of the anti-thiamine factor in bracken leaves (*Pteris aquilina*). The factor, present in the bracken leaves is thermostable, retaining its activity even after heating at 105°C. in air for 18 hours. It is insoluble in ether and acetone, but highly soluble in 92% alcohol (Weswig *et al.*, *loc. cit.*)

The present communication deals with the isolation and study of the kinetics of an active principle, which destroys thiamine, from mustard (*Brassica juncea*).

I. MATERIALS AND METHODS.

Material.—Mustard (commercial variety) was ground to a fine paste in an end runner and freed from oil completely by continuous extraction with ether in soxhlet for 24 hours. The defatted material was spread in porcelain pans and the ether was allowed to dissipate at room temperature under a fan. The de-etherized powder was passed through a 40 mesh sieve. The material thus prepared was used for the isolation of the anti-thiamine factor (A.T.F.).

Determination of the activity of anti-thiamine factor.—The activity of the factor was measured by estimating the amount of thiamine destroyed in a mixture containing thiamine, buffer and the anti-thiamine factor. The thiamine was determined by the thiochrome method (Harris and Wang, 1941). The intensity of the fluorescence was measured in a photo-electric fluorimeter (Lumetron 402 E.F.). The reaction mixture used for the determination of the activity of the factor, unless otherwise stated, was composed of 5 c.c. buffer (*M/5* acetic acid-acetate buffer),

2.5 c.c. thiamine (10 micrograms), 2 c.c. extract (A.T.F.) and water to make the total volume to 10 c.c. The reaction mixture was incubated for one hour at 40°C. and the thiamine was determined in 1 c.c. of the total reaction mixture. Suitable blanks were always run side by side.

The activity of A.T.F. is always expressed as the amount (micrograms) or percentage of thiamine destroyed in the total volume of the reaction mixture after one hour incubation at 40°C.

Thiamine obtained from Hoffmann-La Roche was used throughout this work and all the other chemicals used were of highest grade of purity. In order to avoid the introduction of fluorescent impurities, only glass distilled water of high purity was used.

II. METHOD OF ISOLATION.

1. *Extraction.*—The defatted flour (200 gms.) was added to 1,000 c.c. of chloroform-water mixture (50 c.c. chloroform and 950 c.c. distilled water). The suspension was stirred well for 30 minutes with a mechanical stirrer and allowed to stand overnight at room temperature. Even though the chloroform is a poor solvent for the anti-thiamine factor, its addition during extraction, however, helps the separation of clear extract. It was centrifuged and the residue was discarded.

2. *Removal of inert material at pH 3.0.*—The clear centrifugate was adjusted to pH 3.0 by adding carefully 5N H_2SO_4 drop by drop (the pH was tested with 0.04% Bromphenol blue on a drop plate) and warmed to 60°C. on a waterbath. A heavy precipitate formed, was allowed to settle down and centrifuged. The residue was rejected.

3. *Removal of inert material at pH 8.0.*—The clear centrifugate was adjusted with 20% NaOH to pH 8.0 (tested with 0.04% thymol blue on a drop plate) and warmed to 50°C. The bulky precipitate formed, was allowed to settle down and centrifuged. The residue was discarded.

4. *Precipitation of the active principle with 40% lead acetate.*—The centrifugate was warmed on a waterbath to 50–55°C. and with thorough stirring 40% lead acetate solution (15 c.c.) was slowly added. The heavy precipitate formed was allowed to settle down and centrifuged. The centrifugate was again warmed and 10 c.c. of lead acetate solution were added. It was centrifuged and the centrifugate was discarded. The lead precipitate was collected into a centrifuge tube and washed thrice with distilled water.

5. *Decomposition of the lead compound with H_2SO_4 .*—A fine suspension of lead salt was made in 100 c.c. of distilled water and decomposed by stirring in vigorously 5N H_2SO_4 until the solution was just acedic to Congo red. It was kept on a waterbath for 10 minutes with frequent stirring and allowed to settle down and centrifuged. The precipitate was again suspended in 25 c.c. of distilled water and stirred with two or three drops of 5N H_2SO_4 and warmed and centrifuged. The residue was again treated in the same way with 25 c.c. of water. The combined centrifugates were concentrated to 50 c.c. on a waterbath and allowed to cool down to room temperature and filtered. To this 100 c.c. of absolute alcohol were added and mixed well and allowed to stand at room temperature for 2 hours. It was centrifuged for 30 minutes at a high speed and the precipitate was discarded. It was then concentrated on a waterbath to 20 c.c. and dried completely in a vacuum desiccator over anhydrous calcium chloride. The dried residue was kept overnight in a vacuum desiccator over P_2O_5 to remove the last traces of water.

6. *Extraction with absolute alcohol.*—The dried residue was repeatedly extracted with absolute alcohol (50 c.c.) and was filtered through Whatman No. 42 fluted filter paper. The insoluble matter was rejected. The filtrate was freed of alcohol under reduced pressure and the residue was taken in 50 c.c. of distilled water and was filtered. The clear filtrate, which is brown in colour, is very potent in destroying added thiamine. Neither the active principle nor the colour could be adsorbed on Norite

charcoal. The colour seems to be associated with the active substance and it changes to yellow on the alkaline side.

The anti-thiamine factor is soluble in water and alcohol. It is very sparingly soluble in chloroform and insoluble in ether and acetone.

III. KINETICS.

1. *Effect of concentration of A.T.F. on thiamine destruction.*—The relationship between the rate of action of A.T.F. and its concentration was determined. The reaction mixture contained 5 c.c. buffer (acetic acid-acetate buffer of pH 5.2), 2.5 c.c. thiamine solution (10 micrograms) and varying concentration of A.T.F. and the water to make the total volume of 10 c.c. The reaction was carried out at 40°C. for one hour. The results are presented in Table I.

TABLE I.

Effect of A.T.F. concentration on thiamine destruction.

A.T.F. concentration c.c.	A.T.F. activity expressed as % thiamine destroyed.
0.5	30.1
1.0	52.5
1.5	63.8
2.0	70.6
2.5	81.2

The results show that more destruction of thiamine is effected by the increase in the concentration of A.T.F., but the relationship between the activity and concentration is not linear.

2. *Effect of time on the destruction of thiamine.*—The test mixtures contained 5 c.c. buffer (acetic acid—acetate buffer of pH 5.2) 2.5 c.c. thiamine solution (10 micrograms), 2 c.c. of A.T.F. and water to make up the total volume to 10 c.c. The mixtures were incubated at 40°C. and at known intervals of time 1 c.c. of the reaction mixture was removed and the thiamine estimated. The results are given in Table II.

TABLE II.

Effect of time on the destruction of thiamine.

Time in minutes.	A.T.F. activity expressed as % thiamine destroyed.
1	65.0
15	69.0
30	72.5
45	63.5
60	64.2
12 hours	67.3

It is evident from the results that the inactivation occurs almost instantaneously. 65% of the added thiamine is destroyed even within the first minute. On continuing

the reaction, the increase in the percentage of destruction is not very marked. The reaction is probably not of enzymic nature.

3. *Effect of concentration of hydrogen ions.*—The destruction of thiamine by A.T.F. was carried out between pH 2.7 and 7.5. For pH range between 2.7 to 6.5 *M*/5 acetic acid-acetate buffer was used and for pH between 6.5 to 7.5, *M*/15 phosphate buffer was used. The pH range above 7.5 was not investigated because of the instability of thiamine in alkaline solution.

The results are presented in Table III.

TABLE III.

Effect of pH on the destruction of thiamine by A.T.F.

pH	Time of incubation.	Per cent of thiamine destruction.
2.7	30 minutes	66.8
3.1	"	68.1
3.6	"	66.3
4.5	"	64.2
5.2	"	69.8
6.0	"	65.0
6.5	"	66.7
7.0	"	65.5
7.5	"	63.7

From the results it is clear that the destruction of thiamine is independent of pH between 2.7 and 7.5. This observation also goes to show that the factor is non-enzymic in nature.

Stability of the anti-thiamine factor.

The following experiments were designed to find out its stability (a) towards heat treatments; (b) in alkaline and acid medium. The results are presented in Table IV.

TABLE IV.

Stability of the anti-thiamine factor.

Description of the treatment.	A.T.F. activity as % thiamine destroyed.	Inactivation %.
(a) <i>Effect of heat treatments on A.T.F. activity—</i>		
Control (without any treatment) ..	72.3	....
2 hours at 100°C. ..	72.0	0.3
Autoclaving at 10 lbs. pressure (240°C.)		
for one hour ..	51.2	21.1
Autoclaving at 10 lbs. pressure (240°C.)		
for two hours ..	39.5	32.8
(b) <i>Stability at pH 2.0 and pH 12.0—</i>		
Incubated overnight at 37°C. at pH 2.0 ..	69.9	2.2
Incubated overnight at 37°C. at pH 12.0 ..	46.5	25.8

From the results it is clear that the factor is quite stable at 100°C. On autoclaving for one hour at 10 lbs. pressure (240°C.), 21.1% of the activity is lost and when autoclaved for two hours 32.8% is lost.

The factor is quite stable at pH 2.0 and on incubation at pH 12.0, 25.8% of its activity is lost.

Effect of dialysis on the activity of A.T.F.

20 c.c. of the extract were dialysed in a collodion bag against distilled water for 16 hours at 8°C. After dialysis, the dialysate was concentrated to 20 c.c. on a waterbath. The non-dialysable and dialysable fractions were tested for thiamine-destroying potency. The activity determinations were made according to the method given above and the results are given in Table V.

TABLE V.

Effect of dialysis on the activity of A.T.F.

	A.T.F. activity expressed as % thiamine destroyed
Control	73.0
Non dialysis fraction	24.5
Dialysable fraction (dialysate)	56.0
Non dialysable fraction + dialysate	62.8

The results show that 48.5% of the activity is lost on dialysis for 16 hours and most of the active principle is dialysable. The results indicate that the extract contains two components, one non-dialysable and the other dialysable.

IV. SUMMARY.

1. Mustard (*Brassica juncea*) contains an active principle which destroys thiamine.
2. Method of isolation of the factor has been described. The factor is soluble in water and alcohol. It is sparingly soluble in chloroform, but insoluble in ether and acetone.
3. The relationship between the activity of the factor and its concentration is not linear. Its activity is independent of pH between 2.7 and 7.5.
4. The rate of destruction of thiamine is instantaneous. 65% of the added thiamine is destroyed within one minute.
5. It is quite stable at pH 2.0, but at pH 12.0, 25.8% of its activity is lost.
6. It is stable at 100°C. 21.1% of its activity is lost on autoclaving for one hour at 10 lbs. pressure and 32.8% is lost when autoclaved at the same pressure for two hours.
7. On dialysis, the factor is split into two components, the dialysable component being more active than the non-dialysable.
8. The factor is non-enzymic in nature.

V. ACKNOWLEDGMENT.

I am very grateful to Mr. B. N. Banerjee, Professor-in-charge of the Department of Biochemistry, and to Dr. P. L. N. Rao, Lecturer in Antibiotics, for their helpful suggestions during the course of this investigation and to the Council of National Institute of Sciences for the award of an Imperial Chemical Industries Research Fellowship.

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COINCIDENCE STUDIES OF THE DISINTEGRATION OF NEO-DYMIUM (147), CERIUM (144), PRASEODYMIUM (144) AND CERIUM (143) *

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ABSTRACT

The characteristic radiation energies and coincidence rates of some radionuclides have been determined by conventional absorption and coincidence methods. Beta ray energies have been measured by aluminium absorption and Feather analysis, and the resulting end-points evaluated in terms of energy by Feather's equation. Gamma ray energies were determined by absorption in lead, and in the case of soft quanta in the X-ray region, by absorption in aluminium and lead, and by critical absorption. Beta-beta, beta-gamma, and gamma-gamma coincidence measurements were carried out when possible.

INTRODUCTION

The coincidence rates and radiation energies of several induced activities in the region of the rare earths have been investigated by conventional methods employing G-M counters and absorbers. All of the measured elements were obtained from Oak Ridge as fission fragments or were produced by the exposure of pure target materials to the slow neutron flux in the Oak Ridge pile. Chemical purification was carried out in all cases except that of Nd^{147} which was activated by slow neutron bombardment of exceptionally pure Nd_2O_3 prepared in ion exchange columns at the Institute for Atomic Research, Iowa State College.

The experimental techniques employed have been discussed elsewhere (Mandeville and Scherb, 1948) and will not be described at this time.

Neodymium (147)

The radiations of the 11-day neodymium have been investigated by Marinsky, Glendenin, and Coryell (1947) who have reported beta ray spectra with end-points at 0.4 Mev. and 0.9 Mev. and relative intensities of 40% and 60%, a hard gamma ray at 0.58 Mev., X-rays of energy 40 Kev., and conversion electrons of energy 30 Kev. Other absorption measurements (Muehlhaue, 1947) yielded a beta ray energy of 0.76 Mev. and a gamma ray energy of 0.45 Mev. Cork, Shreffler, and Fowler (1948) give an absorption value of 0.72 Mev. for the gamma radiation and did not find any spectrometric evidence for conversion electrons.

In order to make a thorough study of the radiations from Nd^{147} , Nd_2O_3 was irradiated on three successive occasions in the Oak Ridge pile. A typical decay curve of the induced activity is shown in figure 1 where two periods of 50 hours and 11 days are seen to be present. The decay curve was commenced about three days after removal of the irradiated material from the pile. No energy or coincidence measurements were made until after the 50-hour period had completely disappeared.

* Assisted by the joint programme of the ONR and the AEC.

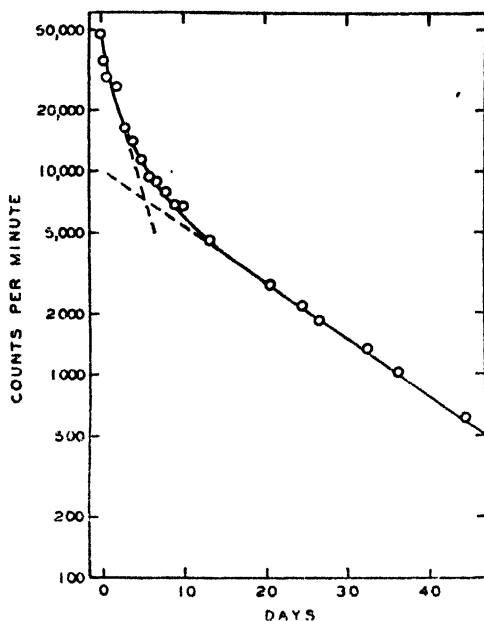


FIG. 1. Decay curve of the activities induced in pure Nd_2O_3 irradiated by slow neutrons in the Oak Ridge pile. Observations were commenced about 36 hours after cessation of irradiation. Two periods are present: the 50-hour promethium and the 11-day neodymium.

The beta rays of Nd^{147} were absorbed in aluminium as shown in figure 2 where two beta ray spectra are clearly present with end-points at 0.17 Mev. and 0.78 Mev.

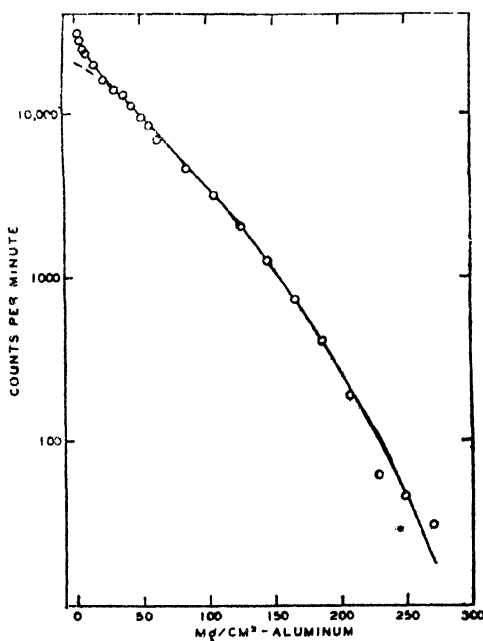


FIG. 2. Absorption in aluminium of the beta rays of the 11-day Nd^{147} . Two groups of particles are present having end-points at 0.17 Mev. and 0.78 Mev.

The precise value of the latter end-point was determined by Feather analysis and Feather's equation (Feather, 1938). Extrapolation of the counting rate of each spectrum to zero absorber thickness as indicated in figure 2 showed that about 33 per cent of the total beta radiation is concentrated in the softer beta ray spectrum.

The absorption curve in lead of the quantum radiations of Nd¹⁴⁷ is shown in figure 3 where a soft component in the X-ray region is clearly present along with a harder gamma ray having an energy indicated by the slope to be 0.58 Mev. The absorption curve in aluminium of the gamma rays of Nd¹⁴⁷ is given in figure 4 where the soft and hard components again appear. From the aluminium absorption curve, the half-value thickness of the soft quanta was found to be 0.33 cm., corresponding to a quantum energy of 35 Kev.

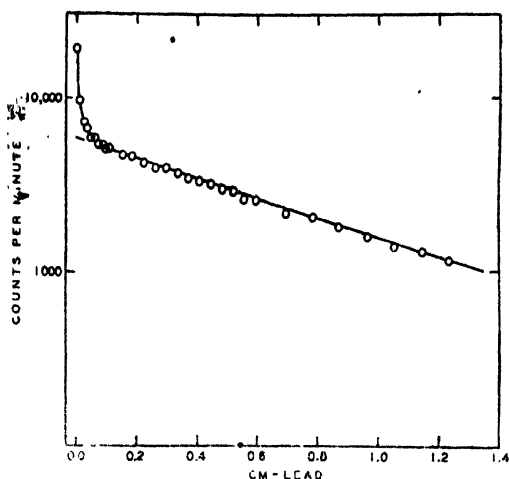


FIG. 3. Absorption in lead of the quantum radiations of Nd¹⁴⁷. A gamma ray of energy 0.58 Mev. is present as well as soft X rays.

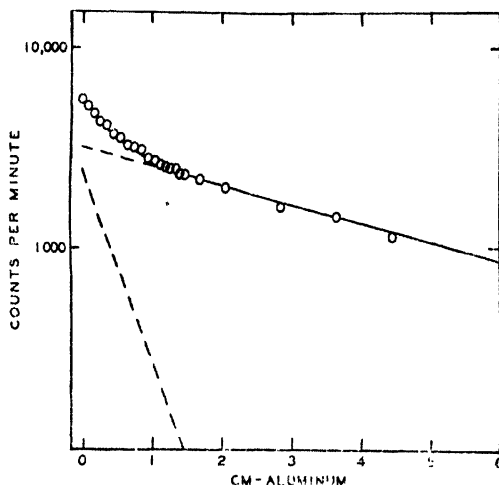


FIG. 4. Absorption in aluminium of the quantum radiations of Nd¹⁴⁷. From this curve the energy of the soft component was found to be 35 Kev.

The intensity of the quanta at 35 Kev. cannot be accurately estimated relative to the harder component, because the quantum efficiency of the counter is not known at 35 Kev.* In order to identify more positively the character of the soft radiations from Nd¹⁴⁷, absorption measurements were carried out using as absorbers solutions of KI, BaCl₂, and LaCl₃. The pronounced absorption in Ba and I as compared to that in La can be taken as an indication that the quantum of energy 35 Kev. is the K α line of promethium, thus indicating that internal conversion takes place in the de-excitation of *Pm¹⁴⁷. The critical absorption data† are shown in figure 5.

* In a previous report (Mandeville, C. E. (1950). Some Characteristics of the 11-Day Neodymium. *Phys. Rev.*, **78**, 319) it was incorrectly stated that the X-rays are fourteen times more intense than the gamma ray at 0.58 Mev. This estimate was based upon the erroneous assumption that the quantum efficiency of the counter was linear with energy even at very low energies. The absorption data were obtained with the use of a counter equipped with a copper cathode so that a high quantum efficiency is developed in the X-ray region owing to the sharp rise in the value of the photoelectric absorption coefficient. The intensity of the X-rays relative to the other quantum radiations is thus exaggerated.

† The X-rays of promethium have been measured by Birkhart, L. E., Peed, W. F., and Spitzer, E. J. (1949). The K-spectra of Element 61. *Phys. Rev.*, **75**, 86-89. The wavelengths of the K α_2 and K α_1 lines are 0.324 AU and 0.319 AU respectively. The K-absorption edges of La, Ba, and I are 0.318 AU, 0.331 AU, and 0.373 AU, so that more absorption would be expected in Ba and I than in La if the soft quanta are composed primarily of the K α radiation of promethium.

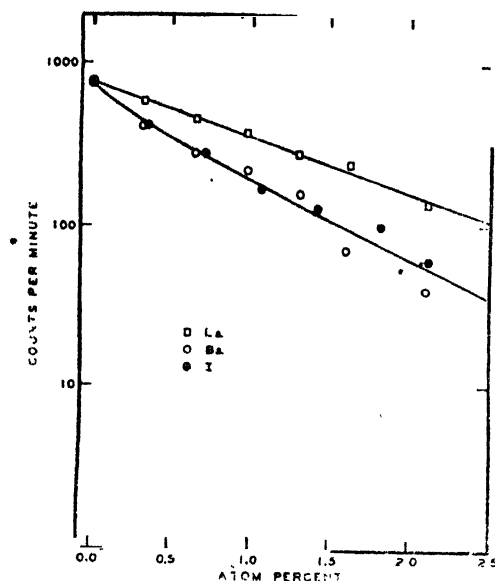


FIG. 5. Absorption in La, Ba, and I of the X-rays emitted in the disintegration of Nd^{147} . From the minimum of absorption in La, it is concluded that at least part of the soft component is composed of the X-rays of promethium.

The beta-gamma coincidence rate of Nd^{147} was measured as a function of aluminium absorber thickness. These data are plotted in figure 6 where the beta-gamma coincidence rate is observed to decrease from an extrapolated value of 0.22×10^{-3} coincidence per beta ray at zero absorber thickness to 0.13×10^{-3} coincidence per beta ray at an aluminium absorber thickness of 25 mg./cm.^2 , remaining constant thereafter. It is evident from this curve that both beta ray spectra of Nd^{147} are coupled with gamma radiation. The beta-gamma coincidence counting

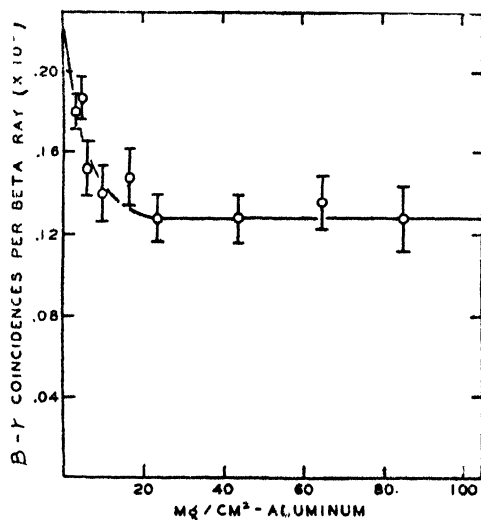


FIG. 6. The beta-gamma coincidence rate of Nd^{147} as a function of the surface density of aluminium placed before the beta ray counter. From this curve, it is concluded that both beta ray spectra are coupled with unconverted quantum radiation.

arrangement was calibrated by the beta-gamma coincidence rate of Sc^{46} (each beta ray followed by 2 Mev. of gamma ray energy) for which the coincidence rate was found to be 2.85×10^{-3} coincidence per beta ray. Assuming that the beta-gamma coincidence rate is directly proportional to the amount of gamma ray energy following each beta ray, the calibration indicates that beyond 25 mg./cm.², each beta ray is followed on the average by 94 Kev. of gamma ray energy. By gamma ray energy is meant, of course, energy in the form of unconverted quantum radiation. Extrapolation of a linear plot to zero absorber thickness is only approximate and always subject to error. However, 0.22×10^{-3} coincidence per beta ray at zero absorber thickness indicates that about seventeen per cent of the total beta radiation is coupled with the hard gamma ray of energy 0.58 Mev., agreeing within a factor of two with the thirty-three per cent estimate obtained from extrapolation of the semi-logarithmic plot of the beta ray spectra shown in figure 2.

A search for beta-beta coincidences was made, but none were found. The combined wall thickness and air path of each beta ray counter used in the beta-beta coincidence measurements was about 6 mg./cm.² Soft conversion electrons having a range shorter than this amount would not have been detected. Since the beta-gamma coincidence data do indicate quanta in coincidence with the harder beta spectrum, and since the X-rays of promethium are very intense, it is concluded that each beta ray of Nd^{147} is followed by several heavily converted γ -rays in cascade, each one of which has an energy of about 0.1 Mev. or less. The lack of beta-beta coincidences does show that the gamma ray at 0.58 Mev. is not appreciably converted.

No gamma-gamma coincidences were detected in Nd^{147} . Whether this can be explained by excessive internal conversion of the cascade gamma rays or by the low quantum efficiency of the counters for soft gamma rays is not certain.

The data concerning Nd^{147} are summarized in the approximate disintegration scheme of figure 7.

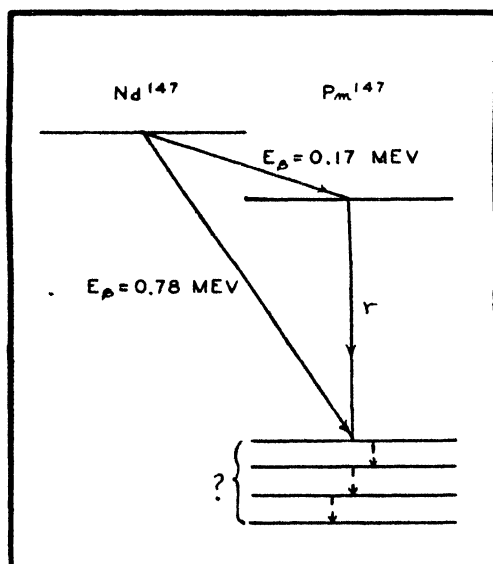


FIG. 7. Partial decay scheme of Nd^{147} .

Cerium (144) and Praseodymium (144).

The 300-day (Born and Seelmann, 1943, Hahn and Strassmann, 1943) Ce^{144} , in equilibrium with its 17-minute daughter element, Pr^{144} , was obtained as a fission

fragment from the Oak Ridge pile. Spectrometric values of 0.348 Mev. (Nedzel and Sampson, 1944) and 0.30 Mev. (Peacock, Jones, and Overman, 1947) have been reported for the beta ray energy of Ce^{144} . Conversion lines at 0.075 Mev. and 0.12 Mev. have been observed in Ce^{144} , but no quantum radiations have been detected (Seiler, Winsberg, and Engelkemeier, 1944).

Absorption measurements of the beta rays of Pr^{144} gave a maximum energy of 3.1 Mev. (Born and Seelmann, 1943; Hahn and Strassmann, 1943). Spectrometric values of 3.07 Mev. (Nedzel and Sampson, 1944) and 2.99 Mev. (Peacock, Jones, and Overman, 1947) have also been reported. Conversion lines corresponding to a quantum energy of 0.135 Mev. have been observed (Nedzel and Sampson, 1944), and gamma rays having energies of 0.22 Mev. and 1.25 Mev. have been measured by lead absorption (Seiler and Winsberg, 1945).

In the course of the present measurements, the beta rays of Ce^{144} in equilibrium with Pr^{144} were absorbed in aluminium as shown in figure 8. Two beta ray spectra are clearly resolved on the semi-logarithmic plot. The softer spectrum has an end-point at 0.10 g./cm.² in aluminium, corresponding to a maximum energy of 0.36 Mev. and is presumably the spectrum of Ce^{144} . A Feather plot of the hard beta rays of Pr^{144} gave a maximum energy of 2.87 Mev. according to Feather's equation.

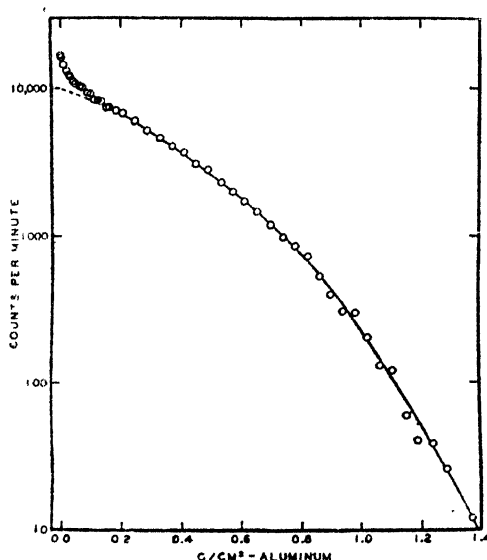


FIG. 8. Absorption in aluminium of the beta rays of Ce^{144} in equilibrium with Pr^{144} . The beta ray energies are calculated to be 0.36 Mev. and 2.87 Mev.

The quantum radiations of Ce^{144} - Pr^{144} were absorbed in lead as shown in figure 9. Two components are clearly present, the harder one having an energy indicated by the slope of the curve to be 1.67 Mev. In a separate experiment, the soft component was absorbed in aluminium and found to have a half-value thickness of 0.36 cm., corresponding to 36 Kev. This is approximately the energy of the $K\alpha$ line in the praseodymium-neodymium region and is taken to be evidence of occurrence of strong internal conversion in one or both of the radionuclides.

The coincidence absorption curve of the recoil electrons of the gamma rays from Ce^{144} - Pr^{144} is given in figure 10 where the end-point is seen to occur at 1.06 g./cm.², denoting, according to a previously determined calibration curve (Mandeville and Scherb, 1948), a quantum energy of 2.60 Mev. Since this very hard gamma ray does not appear on the lead absorption curve of figure 9, it is concluded that it is of

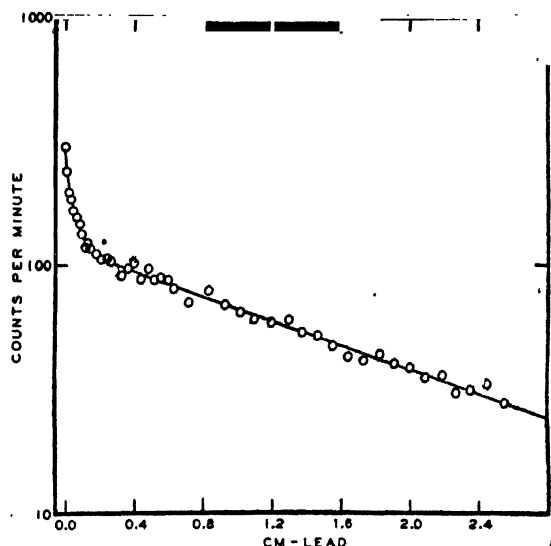


Fig. 9. Absorption in lead of the quantum radiations of $\text{Ce}^{144}\text{-Pr}^{144}$. The presence of X-rays and a gamma ray of energy 1.67 Mev. is indicated.

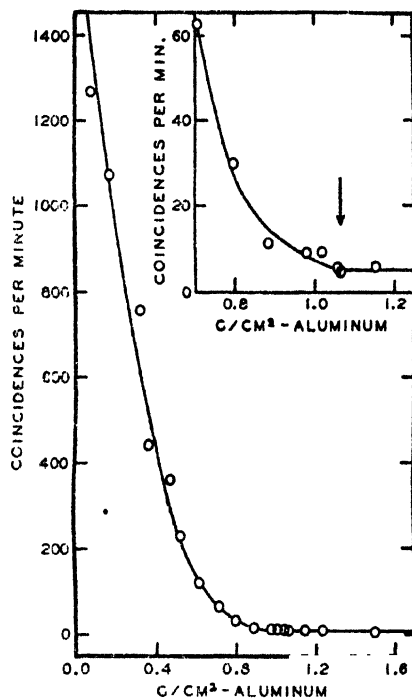


Fig. 10. Coincidence absorption of the secondary electrons of the gamma rays from Pr^{144} . From the end-point of the curve, it is concluded that the maximum gamma ray energy present is 2.60 Mev.

a relatively low intensity *. It is likely that the energy value 1.67 Mev., obtained by absorption in lead, is a weighted mean of the quantum at 2.60 Mev. and a gamma ray of lower energy such as the one at 1.25 Mev. already reported. Since it appears to be well-established that no unconverted gamma rays are emitted in the disintegration of Ce^{144} itself, the hard quanta of figures 9 and 10 are presumed to be emitted by Pr^{144} .

The presence of the hard gamma rays in the decay of Pr^{144} suggests immediately the possibility that the beta-spectrum of Pr^{144} may be complex and that a soft spectrum is present in the decay of Pr^{144} which is coupled with gamma radiation. Accordingly, beta-gamma coincidences were looked for and found in $\text{Ce}^{144}\text{-Pr}^{144}$. The beta-gamma coincidence rate is plotted as a function of aluminium absorber thickness in figure 11 where it is observed to decrease from an extrapolated value of 0.023×10^{-3} coincidence per beta ray at zero absorber thickness to lower values with increasing absorber thickness, showing that a soft beta ray spectrum is indeed present in the disintegration of the 17-minute Pr^{144} . Calibration of the beta-gamma coincidence counting arrangement by the beta-gamma coincidence rate of Sc^{46} led to the conclusion that about two per cent of the total beta radiation of

* The hard gamma ray from $\text{Ce}^{144}\text{-Pr}^{144}$ has been noted by Goldhaber and collaborators (oral discussions by Goldhaber, New York and Washington meetings of the American Physical Society, 1950). They find a somewhat lower spectrometric value of 2.185 Mev. This measurement is confirmed by the fact that they do not observe any photo-disintegration of deuterium by the gamma rays of $\text{Ce}^{144}\text{-Pr}^{144}$.

Pr^{144} lies in the softer spectrum coupled with a total gamma ray energy of about 2.6 Mev. This estimate has been corrected for the presence of the beta rays of Ce^{144} .

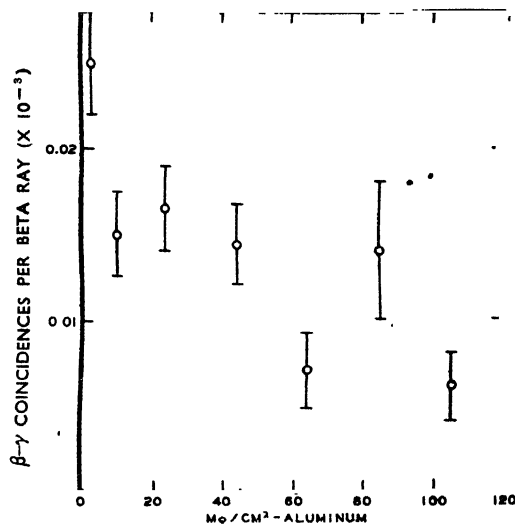


FIG. 11. Beta-gamma coincidences in Pr^{144} as a function of the surface density of aluminium before the beta ray counter. The magnitude of the coincidence rate at zero absorber thickness is such as to suggest that about two per cent of the total beta radiation of Pr^{144} are coupled with about 2.6 Mev. of gamma ray energy. These beta-gamma coincidences were found in Ce^{144} - Pr^{144} and in Pr^{144} freshly separated from the parent element.

To ascertain positively that the observed beta-gamma coincidence rate was in Pr^{144} rather than Ce^{144} , the two elements were chemically separated. The beta-gamma coincidence rate of figure 11 was found in the praseodymium fraction, the half-life of which was observed to be 17 minutes.

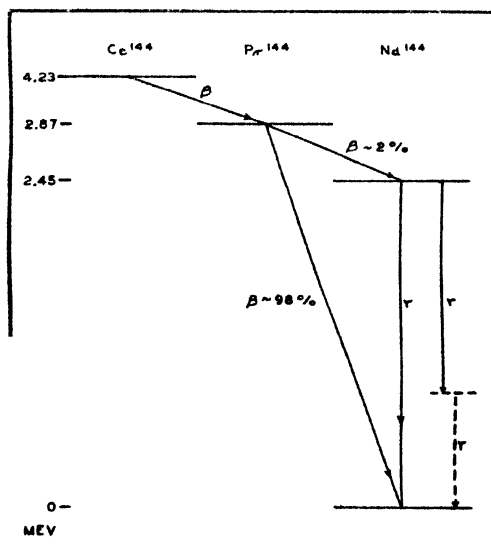


FIG. 12. Disintegration scheme for Ce^{144} - Pr^{144} .

A small gamma-gamma coincidence rate was detected in Pr^{144} (0.08×10^{-3} coincidence per gamma ray) indicating cascade emission of gamma rays in the de-excitation of Nd^{144} . Precautions were taken to eliminate scattering in the gamma-gamma coincidence measurements by placing one millimeter of lead before each gamma ray counter. A search for beta-beta coincidences was carried out in the case of Ce^{144} - Pr^{144} , but after carefully eliminating all scattering effects, no genuine coincidences were found*.

The experimental data concerning Ce^{144} - Pr^{144} are summarized in the term diagram of figure 12.

. . . Cerium (143).

Cerium (143), the 33-hour parent of the 13-day Pr^{143} , was induced in CeO_2 , irradiated for four hours in the Oak Ridge pile. Measurements were commenced

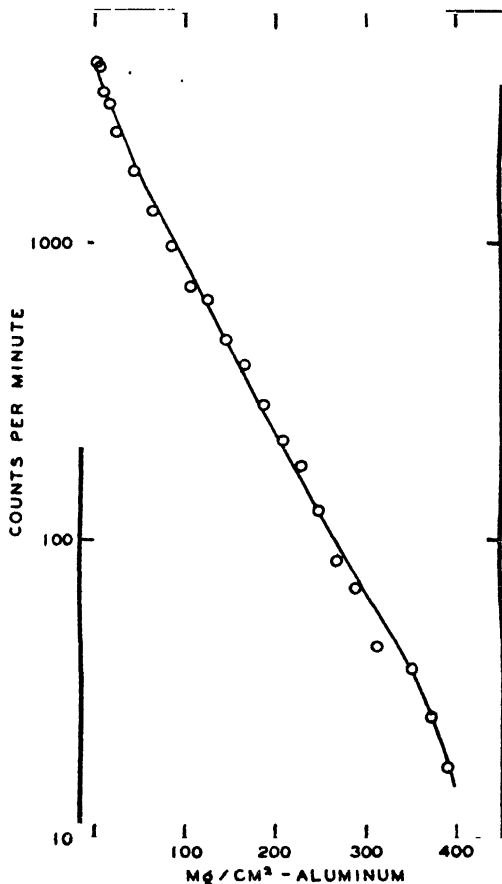


FIG. 13. Absorption in aluminium of the beta rays of the 33-hour Ce^{143} . The maximum energy is 1.24 Mev.

* The two beta ray counters were placed side by side as previously indicated (Mandeville and Scherb, 1948). Even when thus located, scattering between the two counters can lead to the presence of spurious beta-beta coincidences, especially when very hard beta rays are present as in the case of Pr^{144} . This troublesome effect is usually eliminated by mounting the source before the two counters on a very thin backing and by placing the absorbing foils as close as possible, usually contiguous, to the two thin windows of the counters. This latter precaution reduces considerably the possibility that a fast beta particle be back scattered in the first counter, be again back scattered at the absorbing foils, and enter the second counter to give a spurious coincidence.

within 36 hours after removal of the irradiated material from the pile. The exposure time was purposely made short to suppress the 30-day activity of Ce^{141} . Chemical separations were carried out repeatedly during the course of the measurements and just prior to each measurement so as to eliminate any effects arising from Pr^{143} , which reached half-value every 33 hours.

The beta rays of Ce^{143} have been shown to have a maximum energy of 1.36 Mev. (Burgus, 1943) and 1.3 Mev. (Bothe, 1946). Lead absorption curves of the gamma radiation have yielded quantum energies of 0.5 Mev. (Burgus, 1943) and 0.6 Mev. (Pool and Krisberg, 1948).

In the present investigation, the beta rays of Ce^{143} , freshly separated from Pr^{143} , were absorbed in aluminium as shown in figure 13. A Feather plot of these data gave a maximum beta ray energy of 1.24 Mev.

The gamma rays of Ce^{143} were absorbed in lead. These data are plotted in figure 14 where the curve is resolved into three components having energies of 0.87 Mev., 0.20 Mev., and 40 Kev. The very soft quanta are probably X-rays associated with internal conversion.

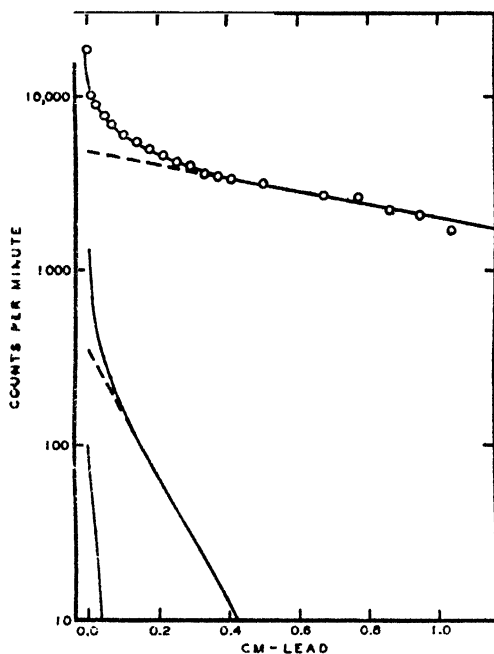


FIG. 14. Absorption in lead of the quantum radiations of Ce^{143} . Three components at 0.87 Mev., 0.20 Mev., and ≈ 40 Kev. are present.

A coincidence absorption curve of the gamma radiation is shown in figure 15. The end-point corresponds to a quantum energy of 0.89 Mev., in satisfactory agreement with the lead absorption data. The ordinates of the curve of figure 15 were observed to decay with the half-period of 33 hours. Growth of Pr^{143} had no effect upon these measurements, because Pr^{143} emits no gamma rays.

The beta-gamma coincidence rate of Ce^{143} is to be seen in figure 16 where it appears to be constant, independent of the beta ray energy. The absolute value of the coincidence rate is such as to suggest that on the average, each beta ray is followed by 0.18 Mev. of gamma ray energy. Since the gamma ray of energy 0.89 Mev. is present, it is very unlikely that the beta spectrum of Ce^{143} is simple. It can

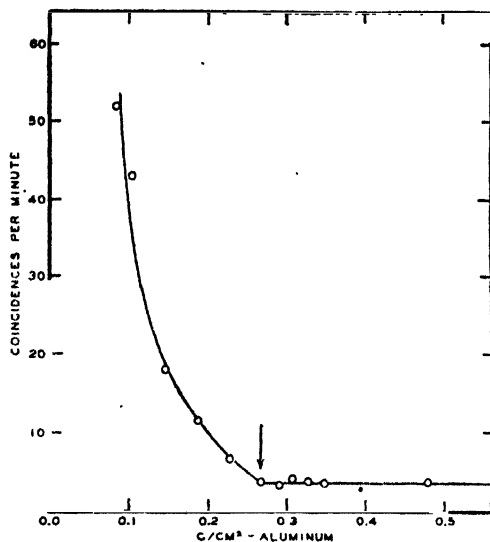


FIG. 15. Coincidence absorption of the secondary electrons of the gamma rays of Ce^{143} . The quantum energy indicated by the end-point is 0.89 Mev.

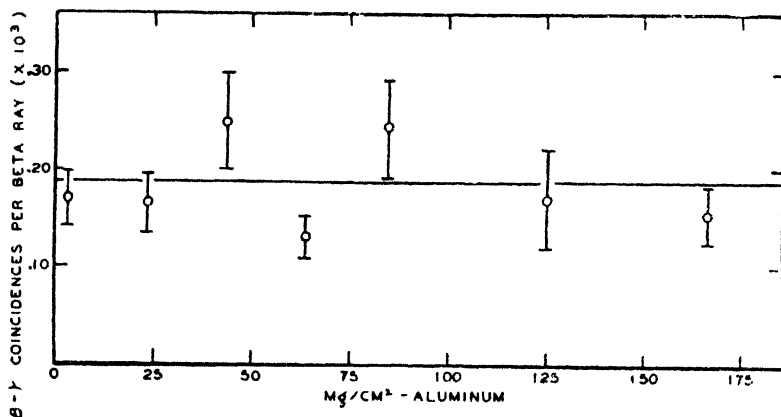


FIG. 16. The beta-gamma coincidence rate of Ce^{143} as a function of the surface density of aluminium placed before the beta ray counter. From this curve it is concluded that each beta ray is followed, on the average, by 0.18 Mev. of gamma ray energy and that few of the beta rays are coupled with the hard gamma ray at 0.89 Mev.

only be concluded that the 0.89 Mev. gamma ray is coincident with only a few per cent of the total beta radiation so that the beta-gamma coincidence curve is not noticeably affected. The number of beta-gamma coincidences per minute were observed to decay with the 33-hour period, giving little evidence of the presence of any Ce^{141} .

APPENDIX I: Separation of Ce^{143} from Pr^{143} .

Pile irradiated ceric oxide and carrier quantities of inactive praseodymium oxide were dissolved in hot concentrated nitric acid to which a few drops of HF were added. An initial purification was made by precipitating the Ce and Pr as

potassium cerium sulfate and potassium praseodymium sulfate. These sulfates were dissolved in hot water, and praseodymium was separated from cerium by precipitating ceric iodate following the procedure of Scott (W. W. Scott, *Standard Methods of Chemical Analysis*, D. Van Nostrand Co., Inc., New York, 1939, 5th ed., pp. 252-253). The ceric iodate was dissolved in hot nitric acid, the resulting solution being treated with oxalic acid crystals to precipitate cerous oxalate which was filtered, washed with alcohol and ether, and dried at 110°C.

APPENDIX II: Separation of Ce^{144} from Pr^{144} .

About 25 mg. of purified cerous oxalate containing Ce^{144} - Pr^{144} was mixed with 30 mg. of inactive praseodymium oxide and dissolved in hot 10N nitric acid. To this solution was added 0.3 g. of solid KBrO_3 and 1.2 g. of KIO_3 in 5N HNO_3 to precipitate ceric iodate. After ten minutes' settling, the suspension was centrifuged for ten minutes and the supernatant was poured into 30 c.c. of a 33% solution of NaOH , precipitating praseodymium hydroxide. The hydroxide was removed by filtration, washed with water, alcohol, and ether.

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ON THE CONSTRUCTION OF MODELS WITH A DISCONTINUITY OF THE MOLECULAR WEIGHT FOR STARS WITH GIVEN VALUES OF THEIR MASS, RADIUS AND LUMINOSITY.

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1. INTRODUCTION.

In recent years considerable attention has been directed to the study of stellar models with a discontinuity of the molecular weight μ somewhere in the stellar material. Schönberg and Chandrasekhar (1942) considered a stellar model with an isothermal core surrounded by an envelope in radiative equilibrium, there being a prescribed discontinuity of the molecular weight across the common interface. Hoyle and Lyttleton (1942, *b*) sought to give a tentative explanation for the structure of red giants by considering the effect on a stellar configuration of a change in molecular weight in the outer region and shewed that under proper restrictions such difference in the atmospheric composition from that of the major part of the mass would cause the star assume a very extensive radius and yet retain its compatibility with the necessary requirements of thermodynamic and mechanical stability. These authors also suggested a mechanism by which the contemplated non-uniformity in the atmospheric composition can be brought about. More recently Ledoux (1947) has examined the effects of a discontinuity in molecular weight occurring in the radiative envelope as well as in the deep interior of a star. He has shewn that in both cases a sharp discontinuity is in general smoothed out and the two regions become separated by a transition zone of variable molecular weight, though a jump in μ of a definite amount is permissible at the outer end of the transition zone. The hypothesis of a sharp discontinuity is indeed a mathematical abstraction, nevertheless the study of solutions of the stellar equations with a sharp discontinuity of μ and satisfying the conditions of stability on both sides of the interface should be considered important from the physical point of view. We assume that such solutions may be associated with configurations physically realisable except for some matters of details.

In the present paper it is proposed to study the problem of the internal constitution of stars on the basis of the convective-radiative model with a sharp discontinuity of composition across the interface. It is easy to see how this difference in composition between the core and the envelope would arise as a consequence of the conversion of hydrogen into helium within the core by the thermonuclear processes responsible for stellar energy generation. The method developed here shews that the equations governing the structure of the star taken along with Bethe's law of energy generation and some very plausible hypothesis regarding the proportion of heavy elements in the stellar material within and outside the convective core, are *just sufficient* to determine the chemical composition of the star from a knowledge of its three observable parameters, viz., its mass (M), radius (R) and luminosity (L). It must not, however, be understood that these equations would always furnish significant solutions for any given L , M , R ; in fact, extremely arduous numerical calculations will be required to decide the point in each individual case. We have attempted to work out in this paper the case of the star α Cen A, but have not

succeeded in obtaining a significant solution. Other stars might probably furnish admissible solutions, but in view of the complexities involved in each calculation a second attempt has not been made.

2. THE EQUATIONS OF EQUILIBRIUM.

The investigations in the present paper are based on the following assumptions:

- (i) The star is a point source model with a convective core surrounded by a radiative envelope.
- (ii) The perfect gas law is valid throughout and radiation pressure is negligible.
- (iii) The chemical composition (and consequently the mean molecular weight μ) is constant in the core and also in the envelope, but there is a sharp discontinuity of μ across the common interface.
- (iv) Photoelectric absorption is the only source of opacity and the guillotine factor in Kramers' formula may be regarded, with reasonable accuracy, as proportional to a power of the density alone (a proper choice of this power will ensure a fair agreement with Morse's table).

The equilibrium equations for the envelope region, embodying the above assumptions, can be written down in the usual notations as

$$\frac{dP}{dr} = \frac{k}{\mu H} \frac{d}{dr} (\rho T) = -G \frac{M(r)}{r^2} \rho \quad \dots \quad (1)$$

$$\frac{dM(r)}{dr} = 4\pi r^2 \rho \quad \dots \quad (2)$$

$$\frac{d}{dr} \left(\frac{1}{3} a T^4 \right) = -\frac{\kappa \rho}{c} \frac{L}{4\pi r^2} \quad \dots \quad (3)$$

Introducing the following representation of the guillotine factor τ (Schwarzschild, 1946),

$$\log_{10} \tau = 0.6 + \log_{10} \rho^{0.25} \quad \dots \quad (4)$$

in Kramers' opacity formula, one gets

$$\kappa = \kappa_0 \rho^{0.75} T^{-3.5} \quad \text{with } \kappa_0 = 1.025 (1+X)(1-X-Y), \quad \dots \quad (5)$$

where X and Y are respectively the hydrogen and helium contents in the stellar material.

The structure of the convective core is governed by the Lane-Emden function of index $n = 3/2$, and the energy production within it according to Bethe's formula gives

$$L = \int_0^{\text{core}} 4\pi r^2 \rho \epsilon \, dr \quad \dots \quad (6)$$

$$\text{where } \epsilon = \epsilon_0 X \rho T^\eta \quad \dots \quad (7)$$

For sunlike stars, $\eta = 17.25$ and $\epsilon_0 = 4.085 \times 10^{-126}$ give a very satisfactory representation of the exact exponential law of energy generation.

3. INTEGRATION OF THE ENVELOPE EQUATIONS.

For purposes of integration it is very convenient to rewrite the envelope equations by introducing the dimensionless variables, p , t , q and x (Schwarzschild, 1946) defined by

$$P = p \frac{GM^2}{4\pi R^4}, \quad T = t \frac{\mu H}{k} \frac{GM}{R}, \quad M(r) = qM, \quad r = xR. \quad \dots \quad (8)$$

Equations (1)—(3) then become

$$\frac{dp}{dx} = -\frac{p}{t} \frac{q}{x^2} \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)$$

$$\frac{dq}{dx} = \frac{p}{t} x^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad (10)$$

$$\frac{dt}{dx} = -\frac{C}{x^2} \frac{p^{1.75}}{t^{8.25}} \quad \dots \quad \dots \quad \dots \quad \dots \quad (11)$$

where
$$C = \frac{3\kappa_0}{4ac} \left(\frac{k}{\mu H G} \right)^{7.5} \left(\frac{1}{4\pi} \right)^{2.75} \frac{L R^{1.25}}{M^{5.75}} \quad \dots \quad \dots \quad (12)$$

Using again $u = \frac{1}{x} - 1$, one obtains

$$\frac{dp}{du} = \frac{p}{t} q \quad \dots \quad \dots \quad \dots \quad \dots \quad (13)$$

$$\frac{dq}{du} = -\frac{p}{t(1+u)^4} \quad \dots \quad \dots \quad \dots \quad \dots \quad (14)$$

$$\frac{dt}{du} = C \frac{p^{1.75}}{t^{8.25}} \quad \dots \quad \dots \quad \dots \quad \dots \quad (15)$$

as the differential equations to be integrated from the boundary inwards, starting with the initial conditions

$$p = t = 0, q = 1, \text{ when } u = 0. \quad \dots \quad \dots \quad \dots \quad (16)$$

These equations will furnish a single parametric set of solutions depending on the value of C chosen.

The integrations may be started by constructing approximate analytic solutions for the variables and can be continued up to a certain depth where the approximation $q = \text{constant} (= 1)$ can still be regarded as valid. The procedure is indicated below.

From (13) and (15) it follows

$$\int_0^t t^{7.25} dt = \frac{C}{q} \int_0^p p^{0.75} dp$$

or
$$\frac{p^{1.75}}{t^{8.25}} = \frac{7}{33} \frac{q}{C} \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$

Now using (17) in (15), one gets after integration

$$t = \frac{7}{33} q u. \quad \dots \quad \dots \quad \dots \quad \dots \quad (18)$$

Equation (17) therefore yields

$$p = C^{-4/7} \left(\frac{7}{33} \right)^{97/7} q^{37/7} u^{33/7} \quad \dots \quad \dots \quad (19)$$

With these values of p and t , equation (14) integrates out to

$$-\int_1^q q^{-30/7} dq = C^{-4/7} \left(\frac{7}{33}\right)^{30/7} \int_0^u u^{26/7} (1+u)^{-4} du$$

$$\text{or} \quad q^{-23/7} = 1 + C^{-4/7} \left(\frac{7}{33}\right)^{30/7} \frac{23}{33} u^{33/7} \left(1 - \frac{33}{10}u + \frac{330}{47}u^2 - \frac{660}{54}u^3 + \dots\right). \quad (20)$$

These expressions can in turn be substituted in the differential equations (13)–(15) and higher approximate solutions derived. The integrations can then be proceeded with by standard numerical methods.

4. STRUCTURE OF THE CONVECTIVE CORE AND CONDITIONS AT ITS BOUNDARY.

It is well known (Chandrasekhar, 1939) that pressure, temperature and mass distribution within an Emden polytrope of index $3/2$ are given by

$$P(\xi) = \frac{k}{\mu H} \rho_c T_c \theta^{2.5} \quad \dots \quad \dots \quad \dots \quad (21)$$

$$T(\xi) = T_c \theta \quad \dots \quad \dots \quad \dots \quad \dots \quad (22)$$

$$M(\xi) = 4\pi \rho_c \left(\frac{5k}{8\pi\mu GH} \frac{T_c}{\rho_c}\right)^{3/2} \left(-\xi^2 \frac{d\theta}{d\xi}\right), \quad \dots \quad (23)$$

where ρ_c , T_c denote the central density and temperature of the configuration respectively. Further the usual radial distance r is connected with the Emden variable ξ by the relation

$$r = \left(\frac{5k}{8\pi\mu GH} \frac{T_c}{\rho_c}\right)^{1/2} \xi \quad \dots \quad \dots \quad \dots \quad (24)$$

The conditions to be satisfied at the interface between the convective core and the radiative envelope are that the pressure, temperature and mass should be continuous across it. The interface being a surface of discontinuity of μ , the first two conditions would also imply the continuity of ρ/μ . Mathematical expressions for these conditions in terms of the variables for the two regions are

$$p_e \frac{GM^2}{4\pi R^4} = \frac{k}{\mu_e H} \rho_c T_c \theta_i^{2.5} \quad \dots \quad \dots \quad \dots \quad (25)$$

$$t_e \frac{\mu_e H}{k} \frac{GM}{R} = T_c \theta_i \quad \dots \quad \dots \quad \dots \quad (26)$$

$$q_e M = 4\pi \rho_c \left(\frac{5k}{8\pi\mu_e GH} \frac{T_c}{\rho_c}\right)^{3/2} \left(-\xi^2 \frac{d\theta}{d\xi}\right)_i \quad \dots \quad (27)$$

where the indices e and i refer respectively to the envelope and core side values on the common boundary.

The following relation fixing the position of the interface will also be available.

$$x_e R = \left(\frac{5k}{8\pi\mu_i GH} \frac{T_c}{\rho_c}\right)^{1/2} \xi_i \quad \dots \quad \dots \quad \dots \quad (28)$$

Equation (6) determining the total energy output inside the core now takes the form

$$L = 4\pi\epsilon_0 X_i \rho_c^2 T_c^{\eta} \left(\frac{5k}{8\pi\mu_i GH} \frac{T_c}{\rho_c} \right)^{3/2} \int_0^{\xi_i} \theta^{\eta+8} \xi^2 d\xi. \quad \dots \quad (29)$$

On the hypothesis that the discontinuity in μ arises on account of the conversion of hydrogen into helium (within the convection zone) it is reasonable to assume the content of heavy elements (apart from hydrogen and helium) $1-X-Y$ as even throughout the whole star. This requires

$$1-X_i-Y_i = 1-X_e-Y_e. \quad \dots \quad (30)$$

Lastly, there is the equation giving the behaviour of the effective polytropic index n , defined by $n+1 = \frac{d \log P}{d \log T}$ on both sides of the interface. Considerations of the sort given by Hoyle and Lyttleton (1946) applied to the present case with the opacity formula (5) lead to the following condition

$$\mu_i^{0.75}(1+X_i)(1-X_i-Y_i)(n_i+1) = \mu_e^{0.75}(1+X_e)(1-X_e-Y_e)(n_e+1). \quad \dots \quad (31)$$

Now $n_i+1 = 2.5$, for a $3/2$ polytrope

and $n_e+1 = \left(\frac{d \log p}{d \log t} \right)_e = \frac{1}{C} \left(\frac{qt^{8.25}}{p^{1.75}} \right)_e$, for the envelope solution,

so that, equation (31) gives, in view of (30),

$$C = \frac{2}{5} \left(\frac{\mu_e}{\mu_i} \right)^{0.75} \frac{1+X_e}{1+X_i} \left(\frac{qt^{8.25}}{p^{1.75}} \right)_e,$$

whence using (12) one finally obtains

$$\frac{3}{4} \cdot 10^{25} \left(\frac{k}{HG} \right)^{7.5} \frac{1}{ac} \left(\frac{1}{4\pi} \right)^{2.75} \frac{LR^{1.25}}{M^{5.75}} (1+X_e)(1-X_e-Y_e) \times \\ \left[2X_e + \frac{3}{4} Y_e + \frac{1}{2} (1-X_e-Y_e) \right]^{7.5} = \frac{2}{5} \left(\frac{1+3X_i+0.5Y_i}{1+3X_e+0.5Y_e} \right)^{0.75} \frac{1+X_e}{1+X_i} \left(\frac{qt^{8.25}}{p^{1.75}} \right)_e. \quad (32)$$

It may be noted that in writing equation (32) the formula

$$\mu = \frac{2}{1+3X+0.5Y} \quad \dots \quad (33)$$

has been taken account of.

Equations (25), (26), (27), (28), (29), (30) and (32) must have to be satisfied in order that a model of the type envisaged may exist for a star with definite values of L , M and R . The model will be completely determined if these seven equations can be solved for the seven quantities T_c , ρ_c , ξ_i , X_i , Y_i , X_e and Y_e ; L , M and R being assumed given. The problem appears to be just determinate though significant solutions may not always exist. It may be remarked here that for a successful solution of the problem an integration of the envelope equations for a suitable value of the parameter C must be provided. The procedure to be adopted for handling these equations will be discussed later.

5. STABILITY OF THE MODEL.

For the present, if the assumption is made that a model has been constructed in conformity with the above requirements, the question of its stability still remains open. We propose to examine this point now.

We start with the observation that a necessary and sufficient condition for the stability of the radiative gradient in a medium with a uniform composition and with a given distribution of density and temperature is the following

$$\left(\frac{d \log P}{d \log T'}\right)_{\text{rad}} > \left(\frac{d \log P}{d \log T'}\right)_{\text{ad}} \quad \dots \quad \dots \quad (34)$$

For stability of the adiabatic gradient, the inequality is reversed. It is known that along any solution of the equations of radiative equilibrium with proper boundary conditions, the effective polytropic index n decreases inwards from the outer boundary of the star, so that, if in any case the convective core begins at a point for which n (radiative) exceeds 1.5 (the corresponding adiabatic index), condition (34) is satisfied and stability of the radiative gradient in the entire envelope region is ensured. A little reflection will shew that in the case of a discontinuity of μ as under consideration here, the two gradients cannot merge and have a common value on the surface of the core. In equation (31) we have set $n_i = 1.5$, which only means an equality of the radiative and adiabatic gradients on the inner side of the interface. If now

$\left(\frac{d \log P}{d \log T'}\right)_{\text{rad}} < 2.5$ everywhere within the core, we have a stable convective core surrounded by a stable radiative envelope, there being a discontinuity of μ across the interface. The problem therefore is to investigate under what conditions $\left(\frac{d \log P}{d \log T'}\right)_{\text{rad}}$, starting with a value 2.5 on the inner boundary of the core, remains

less than this value at all interior points. To calculate $\left(\frac{d \log P}{d \log T'}\right)_{\text{rad}}$ within the core, recourse must be had to equation (1), and equation (3) with $L(r)$ in place of L on the right hand side. These equations give

$$n+1 = \left(\frac{d \log P}{d \log T'}\right)_{\text{rad}} = \frac{16\pi acG}{3\kappa_0} \frac{T^{7.5}}{P\rho^{0.75}} \frac{M(r)}{L(r)} \quad \dots \quad (35)$$

whence one obtains, using the perfect gas law and the polytropic equation of state

$$\frac{\delta n}{n+1} = \frac{\delta M(r)}{M(r)} - \frac{\delta L(r)}{L(r)} + \frac{31}{8} \frac{\delta T}{T}. \quad \dots \quad (36)$$

For an outward step $\delta T < 0$ and $\frac{\delta M(r)}{M(r)} > \frac{\delta L(r)}{L(r)}$ (Hoyle and Lyttleton, 1942a). Hence n will continue to increase outwards so long as

$$\left(\frac{\delta M(r)}{M(r)} - \frac{\delta L(r)}{L(r)}\right) > \frac{31}{8} \left|\frac{\delta T}{T}\right|. \quad \dots \quad (37)$$

In terms of Emden variables θ , ξ , this inequality becomes

$$\left(\frac{\theta^{3/2}}{(-d\theta/d\xi)} - \frac{1}{I(\xi)} \frac{dI(\xi)}{d\xi}\right) > \frac{31}{8} \left|\frac{1}{\theta} \frac{d\theta}{d\xi}\right| \quad \dots \quad (38)$$

where

$$I(\xi) = \int_0^\xi \theta^{7+3} \xi^2 d\xi.$$

Denoting the left hand side of (38) by a function $f_1(\xi)$ and the right hand side by $f_2(\xi)$, and taking $\eta = 17.25$ one obtains the following table for these functions.

ξ	f_1	f_2
0	0	0
0.4	1.415	0.518
0.6	1.908	0.780
0.8	2.185	1.045
1.0	2.197	1.317
1.2	1.999	1.597
1.4	1.703	1.890
1.6	1.409	2.201

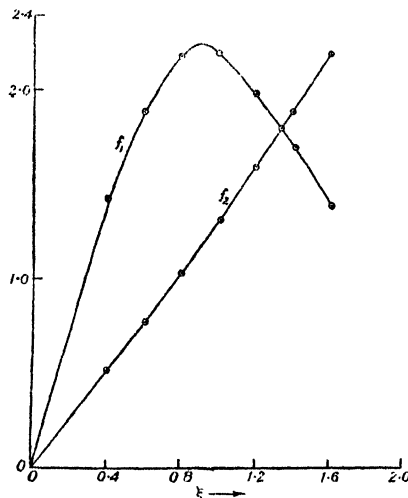


Fig. 1. The functions f_1, f_2 , are plotted against ξ .

It will be evident from a plot of these functions as in Fig. 1 that condition (37) is violated as soon as ξ exceeds the value 1.34. This proves that for any convective core of radius $\xi_i \leq 1.34$, n (starting with a value 1.5 on the inner boundary) will monotonically decrease inwards just in keeping with the requirement of convective stability. This sets an upper limit to the size of the stable convective core for the model we are seeking to build. It is further evident that no stable convective core can begin at an interface $\xi_i > 1.34$. This knowledge is important for the trial and error method we shall adopt below for the solution of our problem.

6. SOLUTION OF THE EQUATIONS OF CONDITIONS ON THE INTERFACE.

We shall now discuss the equations (25), (26), (27), (28), (29), (30) and (32), admissible solutions of which, if any, will completely determine the structure of the star under consideration. The method of solution is one of trial and error. A value of the parameter C in the envelope equations is first selected and the corresponding integrations performed. From the given value of L , the luminosity of the star, an approximate value of the central temperature T_c is guessed. This guess will not be wide off the mark, since the energy generation as controlled by Bethe's law is highly sensitive to T_c . A trial value of the central density ρ_c is now taken. In other words, an attempt is made to solve the equations of fit for a given value of C . Our assumed values of T_c and ρ_c are purely trial values.

Equations (27), (28) yield

$$\left(\frac{q}{x^3}\right) \cdot \frac{M}{R^3} = 4\pi\rho \left(-\frac{1}{\xi} \frac{d\theta}{d\xi}\right); \quad \dots \quad \dots \quad \dots \quad (39)$$

If now the core be supposed to begin at some distance $(x)_0$ along the envelope solution, equation (39) will determine $\left(\frac{1}{\xi} \frac{d\theta}{d\xi}\right)_i$, whence θ, ξ will be obtained by interpolation

in tables of Emden functions for $n = 1.5$. A value of $(x)_e$ should be fixed by trial so as to give ξ_i within the range $1.0 < \xi_i < 1.34$. A value of $\xi_i > 1.34$ is not permissible by stability considerations, and a value < 1.0 should also be left out in view of the fact that the energy integral in equation (29) does not become sensibly constant at this distance. The range of possible values for ξ_i is thus considerably narrowed down by these requirements. Equations (25) and (26) now give μ_i and μ_e which should however satisfy the condition that $\mu_i > \mu_e$ on account of the probable presence of more helium inside the core than outside.* This value of μ_i substituted in equation (29) would then fix X_i . Equation (33), taken with the indices i and e , and equation (30) would together determine X_e , Y_i and Y_e . These quantities should all lie in the range $(0, 1)$ and also $X + Y$ should be less than unity. Lastly, equation (32) should be used as a check for the fit. A violation of this equation would require the whole calculation to be repeated with a different value of $(x)_e$, keeping the guessed values of T_c and ρ_c unaltered. The possibility of a fit by trial with different values of $(x)_e$ (only those values of $(x)_e$ are admissible for which $n_e > 1.5$) should thus be exhausted first. Attempt should then be made to obtain a fit on the same envelope solution with different values of ρ_c . A little practice would enable one to find out the limitations on the possible values of ρ_c . Alterations in the values of T_c should next be attempted. Possible range of variations in T_c will indeed be very small for reasons stated earlier. Finally, the whole sequence of calculations should be repeated with different envelope solutions (for different values of C). Here also by properly taking into account the various causes of failures of the solutions, one can without much difficulty find out the restrictions on the values of C . If any significant solution be still not obtained, the conclusion will be that the equations of fit do not admit a solution for the given values of L , M and R .

In an attempt to construct a model of the type proposed, we have worked out the case of the star α Cen A for which $L = 1.26$, $M = 1.10$ and $R = 1.23$, all in solar units. In a previous paper (Sen and Burman, 1948) on the study of the chemical composition (assumed uniform throughout) of stars on the basis of the Cowling model and Bethe's formula this star was found to present an instance where the equations determining the composition did not offer any significant solutions. We have verified that it is not also possible to determine its composition (supposed uniform) on the basis of Schwarzschild's (1946) model for the sun with the energy generation formula in the form given by Bethe which we have used. For the present work we have constructed numerical solutions of the envelope equations for values of the parameter $C = (2.2427, 2.6427, 3.4427, 3.8427) \times 10^{-6}$. Another integration of the equations for $C = 3.0427 \times 10^{-6}$, provided by Schwarzschild (1946) is also at our disposal. Calculations have been made to obtain solutions of the equations of fit for each of these envelope solutions with values of central temperature in the range $19.5 < T_c < 21.5$ million degrees, and associated central densities in the range $30 < \rho_c < 100$ gm./cm³. Failure in each case arises at the ultimate stage of the calculation on account of the violation of equation (32) which has been used as a check. In constructing the envelope solutions, values of the parameter have been so selected as to cover the range, somewhat above and below Schwarzschild's value. We may group the failures of our trial solutions into two classes. Firstly, there are trial solutions which prove to be incorrect even before our check equation (32) is arrived at, on account of the failure of some necessary conditions for the correct solution as stated above. There is a second class of trial solutions which work out satisfactorily up to the ultimate stage but only fail at the check equation. If we arrange all trial solutions according to the values of the parameter C in the above range, it is found that the solutions of the second class form a series which is bordered on the two sides by trial solutions of the first class.

* Because of production of helium within at the expense of hydrogen.

The range of C thus examined appears to be sufficient and it is permissible to conclude that no proper solution satisfying all the conditions of the problem exists in the case under consideration.

Lastly there remains the pleasant duty of acknowledging grateful thanks to Professor N. R. Sen for many interesting discussions and to the National Institute of Sciences of India, for the award of a Research Fellowship which enabled the author to carry on the work.

SUMMARY.

The problem of the determination of the chemical composition of a star from a knowledge of its mass, radius and luminosity, is studied from the point of view of Bethe's energy generation law, and on the basis of a convective-radiative model with a sharp discontinuity of composition (and hence of molecular weight) across the interface. It is found that just as many equations governing the structure of the star can be framed as there are unknown quantities required for a complete specification of the chemical composition both inside and outside the convective core. Stability consideration sets an upper limit to the size of the convective core for the correct model. It should be noted, however, that the equations referred to above, should not always furnish a significant solution compatible with all the conditions of the problem. In fact, the case of the star α Cen A worked out in this paper leads to no admissible solution.

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RAMANUJAN'S FUNCTION WITH RESPECT TO THE MODULUS 49.

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The function $\tau(n)$ generated by

$$\sum_{n=1}^{\infty} \tau(n)x^n = x \prod_{n=1}^{\infty} (1-x^n)^{24}$$

has a number of remarkable properties many of which were first discovered by Ramanujan. In recent years much attention has been paid to congruence properties of the function $\tau(n)$. Bambah, Banerjee, Chowla, Gupta, Lahiri, Ramanathan, Wilton and others have obtained congruence relations with respect to moduli 2^{10} , 3^5 , 5^3 , 7, 23 and 691. About two years ago the writer noticed, by a study of the values in Watson's table of $\tau(n)$ for $n \leq 1000$ a curious property of $\tau(n)$ with respect to the modulus 49, namely: If p and q are two primes differing by a multiple of 49, then $\tau(p) - \tau(q)$ is also divisible by 49, provided p and q are non-residues of 7. This property, with its unusual proviso, continued to hold without exception when Watson's table was extended to $n = 2500$, but defied attempts at proof. Finally a modification of the methods used previously was hit upon which not only yielded a proof of this property, but also results for the moduli 2^{11} and 3^6 , which will be discussed in another paper. The present note gives a short proof of the 49 property as expressed by the following theorem.

THEOREM. *Let p be a prime congruent to 3, 5, or 6 modulo 7. Then*

$$\tau(p) \equiv 3p(p^3+1) \pmod{49}.$$

It may be shown by referring to tables of $\tau(n)$ that the restriction of p to the abovementioned residue classes modulo 7 is a necessary one and that $\tau(p)$, for p an unrestricted prime, is not congruent to a polynomial in $p \pmod{49}$.

The proof of the Theorem may be considerably shortened by referring to the following definitions and identities of Ramanujan.

$$\Phi_{r,s} = \Phi_{r,s}(x) = \sum_{n=1}^{\infty} n^r \sigma_{s-r}(n) x^n$$

$$P = 1 - 24 \Phi_{0,1}$$

$$Q = 1 + 240 \Phi_{0,3}$$

$$(1) \quad R = 1 - 504 \Phi_{0,5}$$

$$(2) \quad \Delta = 1728 \sum_{n=1}^{\infty} \tau(n) x^n = Q^3 - R^2$$

$$(3) \quad 720 \Phi_{1,4} = PQ - R$$

$$(4) \quad 1584 \Phi_{1,10} = 3Q^3 + 2R^2 - 5PQR = 3\Delta - 5R(PQ - R)$$

$$(5) \quad 41472 \Phi_{4,7} = 3Q^3 + 4R^2 + 7(P^4Q - 4P^3R + 6P^2Q^2 - 4PQR) \\ = 3\Delta + 7(P^4Q - 4P^3R + 6P^2Q^2 - 4PQR + R^2)$$

$$(6) \quad 3617 + 16320 \Phi_{0,15} = 1617Q^4 + 2000QR^2 = 3617QR^2 + 1617Q\Delta$$

$$(7) \quad 1728 \Phi_{2,11} = 6PQ^3 - 5P^2QR + 4PR^2 - 5Q^2R \\ = 6P\Delta - 5R(P^2Q - 2PR + Q^2),$$

where we have made use of (2) to eliminate Q^3 .

Ramanujan noted that the operator

$$\mathfrak{S} = x d/dx$$

has the following properties when applied to $\Phi_{r,s}$, P , Q and R :—

$$\mathfrak{S}\Phi_{r,s} = \Phi_{r+1,s+1}$$

$$12\mathfrak{S}P = P^2 - Q$$

$$3\mathfrak{S}Q = PQ - R$$

$$2\mathfrak{S}R = PR - Q^2.$$

Also

$$\mathfrak{S}\Delta = P\Delta = 12^3 \sum_{n=1}^{\infty} n\tau(n)x^n$$

$$12\mathfrak{S}^2\Delta = (13P^2 - Q)\Delta = 12^4 \sum_{n=1}^{\infty} n^2\tau(n)x^n$$

$$(8) \quad 72\mathfrak{S}^3\Delta = (91P^3 - 21PQ + 2R)\Delta = 6.12^4 \sum_{n=1}^{\infty} n^3\tau(n)x^n.$$

If we operate by \mathfrak{S} on (6) and by \mathfrak{S}^2 on (7) we obtain two further identities in which Q^3 has been replaced by $\Delta + R^2$ in accordance with (2), namely :

$$(9) \quad 12240 \Phi_{1,16} = (1617PQ - 3117R)\Delta + 3617R^2(PQ - R)$$

$$(10) \quad 20736 \Phi_{4,13} = (156P^3 + 104PQ - 53R)\Delta - 65R(P^4Q - 4P^3R \\ + 6P^2Q^2 - 4PQR + R^2).$$

Multiplying (10) by 7 and substituting from (5) gives

$$(11) \quad 145152 \Phi_{4,13} = 7\Delta(156P^3 + 104PQ) - 176R\Delta - 2695680R\Phi_{4,7}.$$

We now begin to consider the above identities with respect to the moduli 7 and 49. As usual, we denote by J a power series in x with integer coefficients and write (1), (2), (5), (8), (9) and (11) as follows :

$$(1') \quad R - 1 = 7J$$

$$(2') \quad 13 \sum_{n=1}^{\infty} \tau(n)x^n = \Delta + 49J$$

$$(5') \quad \Phi_{4,7} + \Delta = 7J$$

$$(9') \quad 39\Phi_{1,16} = 19R\Delta + 40R^2(PQ - R) + 49J$$

$$(11') \quad 14\Phi_{4,13} = (14P^3 - 7PQ)\Delta + 20R\Delta + 6R\Phi_{4,7} + 49J$$

and finally

$$(8') \quad 24\mathfrak{S}^3\Delta = (14P^3 - 7PQ)\Delta + 17R\Delta + 49J = 18 \sum_{n=1}^{\infty} n^3\tau(n)x^n + 49J.$$

From (1') it follows that

$$(1'') \quad R^2 = 2R - 1 + 49J$$

Multiplying both members of (9') by 18 we have

$$\begin{aligned} R\Delta &= 34R^2(PQ - R) + 33\Phi_{1,16} + 49J \\ &= 34(2R - 1)(PQ - R) + 33\Phi_{1,16} + 49J \\ &= -30R(PQ - R) + 15.720\Phi_{1,4} + 33\Phi_{1,16} + 49J \\ &= 6.1584\Phi_{1,10} - 18\Delta + 20\Phi_{1,4} + 33\Phi_{1,16} + 49J \end{aligned}$$

by (1''), (3) and (4). Hence

$$(12) \quad R\Delta = 31\Delta + 33\Phi_{1,16} - 2\Phi_{1,10} + 20\Phi_{1,4} + 49J.$$

Subtracting (11') from (8') gives

$$(13) \quad 18 \sum_{n=1}^{\infty} n^3\tau(n)x^n = 14\Phi_{4,13} - 3R\Delta - 6R\Phi_{4,7} + 49J.$$

Multiplying (1') and (5') together we get

$$(14) \quad R\Phi_{4,7} = -R\Delta + \Delta + \Phi_{4,7} + 49J.$$

Substituting (14) into (13) we find

$$\begin{aligned} 18 \sum_{n=1}^{\infty} n^3\tau(n)x^n &= 14\Phi_{4,13} + 3R\Delta - 6\Delta - 6\Phi_{4,7} + 49J \\ (15) \quad &= 38\Delta + 14\Phi_{4,13} + \Phi_{1,16} - 6\Phi_{1,10} - 6\Phi_{4,7} + 11\Phi_{1,4} + 49J \end{aligned}$$

by (12). Multiplying (15) by -2 we get

$$(16) \quad 13 \sum_{n=1}^{\infty} n^3\tau(n)x^n = 22\Delta + 21\Phi_{4,13} - 2\Phi_{1,16} + 12\Phi_{1,10} + 12\Phi_{4,7} + 27\Phi_{1,4} + 49J.$$

From (5') we have

$$(17) \quad 21\Delta = -21\Phi_{4,7} + 49J$$

Also

$$(18) \quad \Phi_{4,13} = \sum_{n,m} n^4 m^{13} x^{mn} = \sum_{m,n} n^4 m x^{mn} + 7J = \Phi_{1,4} + 7J.$$

In view of (17), (18) and (2'), (16) can be written

$$(19) \quad 13 \sum_{n=1}^{\infty} (n^3 - 1)\tau(n)x^n = 40\Phi_{4,7} - \Phi_{1,4} - 2\Phi_{1,16} + 12\Phi_{1,10} + 49J.$$

Multiplying both sides of (19) by 34 and identifying coefficients of x^n on both sides of the equation we get

$$(20) \quad (n^3-1)\tau(n) \equiv 30n\sigma_{15}(n) + 16n\sigma_9(n) - (12n^4-15n)\sigma_3(n). \quad (\text{mod } 49).$$

For $n = p$, a prime, (20) becomes

$$\begin{aligned} (p^3-1)\tau(p) &\equiv 30p(p^{15}+1) + 16p(p^9+1) - (12p^4-15p)(p^3+1) \quad (\text{mod } 49). \\ &\equiv 3p(p^3+1)(p^3-1)(10p^9-p^3-4) \quad (\text{mod } 49). \end{aligned}$$

Now if p is a non-residue of 7, as provided in the hypothesis, then $p^3 \equiv -1 \pmod{7}$ so that the factor (p^3-1) is prime to 49. Moreover p^3+1 is a multiple of 7 so that the last factor $10p^9-p^3-4$ may be replaced by what it is congruent to modulo 7, namely unity. Dividing by p^3-1 therefore gives

$$\tau(p) \equiv 3p(p^3+1) \quad (\text{mod } 49)$$

which is the theorem.

Two immediate consequences of the theorem may be noted.

COROLLARY 1. *If p is a prime, $\tau(p)$ is divisible by 49 if and only if $p \equiv 19, 31$, or $48 \pmod{49}$.*

Proof: From (5') follows the well-known fact that

$$\tau(n) \equiv n\sigma_3(n) \quad (\text{mod } 7).$$

If $n = p$, we see that $\tau(p)$ is divisible by 7 if and only if p is a non-residue of 7. Applying our theorem, for $\tau(p)$ to be divisible by 49 it is necessary and sufficient that

$$p^3 \equiv -1 \quad (\text{mod } 49).$$

The three roots of this congruence are those specified in the conclusion of the corollary.

The second result is a curious congruence property for the sum

$$\Sigma_n = \sum_{\substack{u+7v=n \\ u, v > 0}} \sigma(u)\sigma_3(7v).$$

This function occurs in an expression for $\tau(n)$ modulo 49 given by Bambah and Chowla:

$$\tau(n) \equiv 8n^4\sigma_3(n) - 14\{2(1-n-n^3)\sigma_3(n) + (2n^2-3)\sigma(n) + \Sigma_n\} \quad (\text{mod } 49).$$

If we take the case of n a prime p which is a non-residue of 7 and apply our theorem the following congruence results.

$$7 \Sigma_p \equiv 5p(p+1)(p-3)(p-5) \quad (\text{mod } 49).$$

In conclusion it should be noted Gupta's conjecture that if p is a prime non-residue of 7 then

$$\tau(p)/7 \equiv r-1-[3/r]-2q \quad (\text{mod } 7) \quad (p = 7q+r)$$

follows from our theorem by a simple consideration of each of the three cases of $r = 3, 5$ and 6 .

A REVIEW OF THE INDIAN OIL SARDINE FISHERY.¹

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INTRODUCTION.

It is well known that the European and American herring, pilchard, sardine, etc., make the largest contribution to the fisheries of the world, and are the mainstay of the economy of most of the European maritime nations. The French expression 'la crise sardinière' is a measure of the disastrous effect of the failure of the fishery to the nation. The pioneering fishery researches of Scandinavian countries to elucidate the causes of the periodical failure of the herring fishery indicate the importance attached to this fishery. The 'iwashi' or Japanese sardine yields more than a million tons during a normal season in a year. The sardine fishery of the Pacific Coast of North America came to prominence as a result of the stress of World War I and contributes the largest output of any single fish in the State of California.

In Indian waters, the clupeoids are chiefly represented by sardines, anchovies and whitebaits, of which the oil sardine, *Sardinella longiceps* Cuv. & Val., ranks as the most valuable and highly priced fish in the economy of the West Coast of India, from Ratnagiri in the North to Travancore in the South. From the Malabar Coast the sardine oil and manure were exported for over a century and the fish has been rightly referred to as 'Kudumbam pularthy' (provider for the family) in the Malayalam language.

The fluctuations in the Indian oil sardine fishery were similar to those of the herring and sardine fisheries of Europe, America and Japan, with the yields undependable. The abundant occurrence of oil sardines all along the West Coast and their use as food and manure had been known from very early times. Odoric² was probably referring to the oil sardines when he observed, during his visit to Ceylon about the year 1320, that 'there are fishes in those seas that come swimming towards the said country in such abundance, that for a great distance into the sea nothing

¹ Published with the permission of the Chief Research Officer, Central Marine Fisheries Research Station, Mandapam Camp and the Director of Fisheries, Madras.

² Cited by Day (1865).

can be seen but the backs of fishes, which, casting themselves on the shore, do suffer men for the space of three daies to come and take as many of them as they please'. Nieuhoff¹ also noted in 1673 that the oil sardines were abundant off Malabar and Ceylon. Dussumier,² in the year 1827, observed in Malabar the sardines being used as manure for paddy and coconut palms as they were unfit for salt-curing owing to excess of fat. Day (1865) remarked that 'it is only of late years, since animal oils have become so dear, partially due to a deficiency of that of the whale, that attention has been directed to the immense shoals of sardines, which are found off Malabar and Ceylon'. He also observed that until after the middle of the 19th century the sardines were largely used for manuring coconut plantations and paddy fields, for feeding pigs and poultry and for manufacturing oil; while a comparatively small proportion of the catches alone was consumed by the local population. Judging from the annual average value (£7,000) of export of sardine oil from Malabar to Europe and other places, it would seem that these fishes were caught mainly for oil. The high price of oil sustained the industry on the West Coast of India, but Day foresaw the ill-effects of unrestricted fishing in diminished catches in later years. He also thought that the oil sardines 'occasionally forsake their haunts for several consecutive seasons, returning again in enormous quantities'. Thurston (1900) attributed the declining trade in oil to irregularity in the appearance of sardines. Nicholson (1915) suggested the revival of the oil industry on more rational lines.

FISHERY.

The oil sardine fishery is restricted to a 8 to 10 mile broad strip of the inshore waters off the Kanara and Malabar Coasts, owing to the small size of the craft used for fishing such as the dug-out canoe. The size of tackle used had naturally some relation to the size of craft employed, but within the implied limitations, maximum efficiency for capturing the shoaling oil sardines in inshore waters was attained in the course of several years. The fishing season extends from August to March, but the September to December portion of the season is the best.

Fishing Methods.

Up to about 1895, oil sardines were caught in boat seines ('Paithu vala', 'Odam vala', etc.), drift nets ('Ozhuku vala', 'Kora vala', etc.) and cast nets, but other types of seines and gilling nets were later introduced on the West Coast. With the installation of fish oil and guano factories in 1908, these more effective new types of gear came into vogue fetching better prices for catches landed late in the evenings even beyond 10 p.m. when demand for fresh fish for consumption or curing would be the lowest. Moreover, the demand from the factories of even stale fish induced the fishermen to go for regular night fishing. The local names, dimensions and other specifications of the introduced nets are given below:—

Name.	Length in ft.	Width in ft.	Mesh size in inch.	Material.
I. Seine net:—				
1. Kolli vala:—				
(a) Mathikolli vala ..	60	18	$\frac{1}{2}$	Hemp
(b) Ailakolli vala ..	50	30	$\frac{1}{2}$	do.
2. Rampani ..	1,800	15-20	$\frac{1}{2}$ -1 $\frac{1}{2}$	do.
II. Gilling net:—				
1. Mathichala vala ..	36-90	12-18	$\frac{3}{4}$ - $\frac{5}{8}$	Cotton
2. Ailachala vala ..	48-60	30-36	$\frac{7}{8}$ -1	do.

1 & 2 Cited by Day (1865).

Two canoes with a total crew of fourteen carry in each boat half the seine net. When the shoal is sighted it is usual to pay out the net from both the canoes, which at the same time separate to form a semi-circle. When the shoal is encircled they move in towards each other and haul the net. The 'Kolli vala' is operated in the same manner, but the shoals are literally frightened and driven into the net by the loud noise and splashing made by the fishermen. 'Rampani', being a large shore seine, is operated by 70 to 80 men working from the shore with the assistance of 8 to 10 men on a large boat in the sea. Gillig nets are laid from two canoes in a slightly semi-circular fashion across the direction of the movement of the shoal, and the shoal driven towards them with plenty of noise. Cast nets are used from boats only, when large shoals are sighted at the surface.

Fishing Centres.

The important oil sardine centres of South Kanara and Malabar Districts on the West Coast are Malpe, Udiawar, Adakathbail, Madai, Cannanore, Tellicherry, Badagara, Quilandy, Calicut, Parapanangadi, Tanur, Ponnani, Blangad, Mannalam-kunnu and Kadapuram.

Fluctuations in the Fishery.

The capricious nature of the fishery on the South Kanara and Malabar Coasts will become obvious when we examine the following tabulated statements of the recorded quantities of fish oil and guano manufactured and exported during several years, and of cured fish and the estimated total landings of oil sardine during the last 25 years.

Export figures of sardine oil from the port of Cochin, the chief exporting centre of the Malabar Coast, from 1840-41 to 1863-64 (Day, 1865).

				Maunds ¹
Average for 5 years ending	1845-46	..	..	92
"	1850-51	..	..	5,020
Year	1855-56	..	..	63
"	1856-57	..	..	252
"	1857-58	..	..	95,900
"	1858-59	..	..	1,44,094
"	1859-60	..	..	1,86,400
"	1860-61	..	..	..
"	1861-62	..	..	..
"	1862-63	..	..	161
"	1863-64	..	..	2,07,488

It is evident that in the years 1857-58 to 1859-60 and 1863-64 the oil sardine fishery was good.

Statistics of fresh and sun-dried oil sardines used in coffee plantations and collected by agents of Messrs. Arbuthnot & Co., Ltd. (Thurston, 1900).

Seasons.	Fresh fish.	Sun-dried fish.
1890-91	4,620 Mds.	952 Mds.
1891-92	2,100 "	2,352 "
1892-93	4,424 "	4,060 "
1893-94	5,544 "	40,404 "
1894-95	1,176 "	49,392 "
1895-96	4,648 "	45,500 "
1896-97	504 "	..
1897-98	672 "	..

The success of the fishery between 1893 and 1896 is quite obvious.

Quantities of oil sardines cured in fish-curing yards between 1896 and 1907 (Hornell, 1910).

							Maunds.
1896	..	..	..	..	..	..	3,87,295
1897	..	..	..	..	..	..	2,53,649
1898	..	..	..	..	..	..	28,702
1899	..	..	..	..	..	Poor year for sardines.	
1900	..	..	..	..	..	..	57,880
1901	..	..	..	..	..	..	1,37,190
1902	..	..	..	..	..	..	2,19,760
1903	..	..	..	..	..	..	1,85,160
1904	..	..	..	..	..	..	1,33,200
1905	..	..	..	..	..	..	1,26,080
1906	..	..	..	..	..	..	1,48,259
1907	..	..	..	..	..	..	2,79,821

The immensity of the catches of oil sardines in 1899, which was considered as a poor year for sardines by Hornell (1910) can be well judged when compared to the catches of recent years. 5,320 maunds of oil sardines were landed in Ponnani circle, in the first week of December 1899 against 12,880 maunds in the first fortnight of December 1933 which was the best season for oil sardines since 1925. The prices provide a good index of the then prevailing abundance of oil sardines—15 and 200 sardines per pie in the poor and good years respectively of the nineties of the last century as against 20 sardines for a pie in the good year of 1933.

In the absence of records of landings of oil sardines for the period 1907-08 to 1924-25, the following statement showing the production of sardine oil and guano on the West Coast would give an approximate idea of the landings during the period:—

Seasons.	Oil in maunds.	Guano in maunds.
1906-07	..	1,60,216
1907-08	..	3,75,212
1908-09	..	..
1909-10	..	..
1910-11	..	5,264
1911-12	..	7,476
1912-13	..	52,416
1913-14	42,308	1,32,328
1914-15	..	..
1915-16	14	70
1916-17	..	..
1917-18	..	..
1918-19	..	..
1919-20	..	67,200
1920-21	..	42,000
1921-22	..	28,000
1922-23	3,36,000	8,96,000
1923-24	2,03,000	6,30,000
1924-25	56,000	1,12,000
1925-26	1,39,440	2,75,800

It would appear from the above that there have been good years and bad years for the sardine fishery throughout the entire period. It was reported ¹ that the season

¹ Report of the Committee on Fisheries in Madras, 1929, 71.

of 1925-26 was a poor year when the quantity of guano produced amounted to 2,75,800 maunds; and the estimated total landings of oil sardine during the year were 11,92,449 maunds. If this quantity was considered as poor, one could very well imagine the magnitude of the oil sardine fishery in good seasons prior to 1925-26. For instance in 1922-23 the quantity of oil sardines utilized for manufacture of guano alone amounted to not less than 45 lakhs of maunds; this figure excludes the quantity consumed as fresh fish, utilized for curing, etc. Subsequently only in 1933-34 the landings had been heavy amounting to more than 19 lakhs of maunds when a relatively low quantity of 2,80,000 maunds of guano was manufactured.

Statement of estimated landings of oil sardines from the fish-curing yard registers in the South Kanara and Malabar Districts.

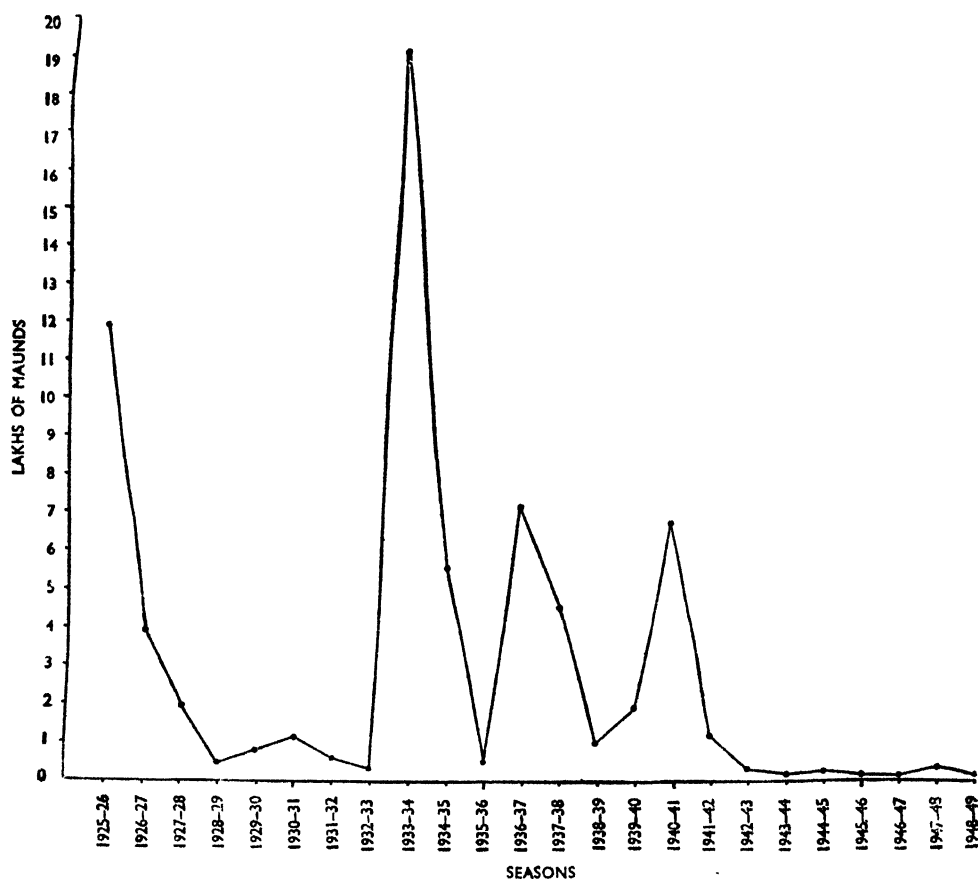
Seasons.	Oil sardines landed in maunds.		Total in maunds.
	South Kanara.	Malabar.	
1925-26	6,50,707	5,41,742	11,92,449
1926-27	74,021	3,22,626	3,96,647
1927-28	63,673	1,29,339	1,93,012
1928-29	8,465	39,968	48,433
1929-30	42,122	31,656	73,778
1930-31	4,824	1,11,048	1,15,872
1931-32	17,175	41,378	58,553
1932-33	212	29,901	30,113
1933-34	7,96,805	11,26,788	19,23,593
1934-35	10,796	5,47,414	5,58,210
1935-36	961	39,188	40,149
1936-37	1,22,365	6,05,361	7,27,726
1937-38	76,445	3,79,592	4,56,037
1938-39	66,873	24,576	91,449
1939-40	78,240	1,11,724	1,89,964
1940-41	2,90,603	3,86,406	6,77,009
1941-42	13,442	1,05,789	1,19,231
1942-43	690	23,948	24,638
1943-44	5,867	5,991	11,858
1944-45	17,472	123	17,595
1945-46	195	281	476
1946-47	30	207	237
1947-48	25,494	6,419	31,913
1948-49	6,645	1,144	7,789
1949-50	16,083	74,744	90,827

Taking into account that only 28.9 per cent of the landings were cured¹ in the fish-curing yards and also that 5 maunds of fish were required for the manufacture of 1 maund of guano,² landings of oil sardines had been as heavy as 1 million maunds or more in the years 1896-97, 1907-08, 1912-13, 1919-20, 1922-23, 1923-24, 1925-26 and 1933-34. The average annual catches of oil sardines were estimated by Nicholson (1918) as 28,00,000 maunds. The maximum quantity recorded during the period 1925-26 to 1948-49 was 19,23,593 maunds in 1933-34, much below Nicholson's estimate. And only in another season, 1925-26, the landings had exceeded one million maunds. The catches had fallen down to less than 50,000 maunds in 1928-29, 1932-33, 1935-36 and 1942-43 and thereafter. The lowest catch recorded prior

¹ Brochure on the Marketing of fish in India, 1948, 32

² Madras Fish. Bull., Vol. 13, No. 3, 1922, 182.

to 1942-43 was 30,113 maunds in 1932-33, and in no year after 1941-42 had this figure been exceeded except in 1947-48 and then only by 1,800 maunds. Even though the fishery was fluctuating between 30,113 maunds in 1932-33 and 19,23,593 maunds in 1933-34, the fishery proved to be disastrous after 1941-42 (Graph).



Graph showing the fluctuations in the annual landings of the oil sardine in the South Kanara and Malabar Coasts from 1925-26 to 1948-49.

The average annual landings for the five-year period between 1937-38 and 1941-42 was 3,06,738 maunds against the lowest record of 237 maunds in 1946-47. The figures for the year 1949-50 show a rising tendency again with the landings about seven times the average for the bad years from 1942-43 to 1948-49.

Legislation.

The decline in the fishery in certain years may be attributed to (1) the fluctuations in abundance, (2) periodical migrations into offshore regions, (3) heavy natural mortality or overfishing, etc. The remedy for some of these will naturally result in evolving suitable legislation. The object of fishery legislation is only for the preservation of the continuity of the supply of fish and the object of the bye-laws is to prevent the destruction of undersized and immature fish so as to preserve a sufficient number of adults to secure a continuous supply. The biological ideal

would be to allow every individual fish to spawn at least once, but this is not practicable. It appears to us that the best means to achieve a continuous supply will be (1) to prevent the capture of fish below a certain size, (2) to establish close seasons, (3) to prohibit the capture or removal from a fishery of adults whilst engaged in reproduction, and (4) to prohibit the highly destructive methods of fishing.

The fluctuations in the oil sardine fishery had been attributed to various causes by workers on the subject. Day (1865) thought 'it must be left for future years to demonstrate whether the present increase of this fish oil trade is a healthy or an unhealthy stimulus due to the present high prices; for if the latter, the fisheries are being overworked, and the future loss will be great. The extreme violence of the South-West monsoon of course protects the fish from the commencement of June until September, but the periods of year at which the various species spawn, more extended observations on their arrival and departure, and a thorough examination into the fish captured as to whether the young are or not used for salting or fish oil, are objects which it would be very important to ascertain'. Thurston (1900), Hornell (1910) and Nicholson (1915) seem to have ignored altogether the overfishing problem. Sundara Raj¹ thought that the capture of large numbers of immature sardines would affect the fishery prejudicially and that overfishing of oil sardines would not arise as the existence of one or more races of oil sardines remained to be investigated. Devanesan (1943) and Devanesan and Chidambaram (1948) suggested respectively overfishing and the intrusion of an immature generation in the fishery as the probable causes of fluctuation. The variety of opinions expressed on the erratic nature of the fishery led to the study of the effect of the different kinds of nets employed. An investigation of this kind by one of us (K. C., unpublished) during the period 1933-34 to 1941-42 showed that only fish 15 cm. long or more were taken in the large meshed gilling net 'Chala vala' and immature sardines, less than 15 cm. long, in the boat seine 'Kolli vala'. That the 'Kolli vala' and 'Chala vala' introduced on the Malabar Coast about the year 1895 had a deleterious effect on the oil sardine fishery was realized by the fishermen who protested against the use of such nets and submitted petitions to Government. The use of these nets was also forbidden by fishermen's panchayat in some villages in Malabar. The fishermen believed that the noise made during the operation of the 'Mathikolli vala' and 'Mathichala vala' frightened the shoals of sardines and other fishes which receded to deeper waters.

Moreover, in the years of abundance from 1907 onwards, as shown in the statements given above, it would appear that small and immature sardines largely contributed to the fishery and the causes for the large demand for sardines were the high oil content of even small sized sardines below 15 cm. in length and the high prices offered by the oil and guano factories for such small sized fishes. The concentrated efforts made by fishermen, leading also to increased night fishing, to meet this demand may have affected the stock to a considerable extent apart from a fortuitous combination of unfavourable conditions in the sea. Examination of a few samples of oil sardines from Aden, Muscat, Karachi, Bombay and Karwar by Devanesan and Chidambaram (1943, abstract) showed that more than one race might occur but it needs careful examination.

As a result of consideration of the several different factors involved the Government of Madras introduced restrictive legislation in 1943 in the Malabar and South Kanara Districts. The main clauses relate to the prohibition of (1) the use of 'Mathikolli vala', during the fishing season from August to April, (2) the use of 'Mathichala vala' during the spawning period in August and September, and (3) the landings of immature oil sardines below 15 cm. not exceeding a total weight of 1 maund from any single boat during the fishing season. The legislation was extended for another two years from 1945 to prohibit the use of these nets for the capture of

¹ Administration Reports for the years 1933-34 and 1936-37 of the Madras Fisheries Department.

immature oil sardines throughout the year. The legislation lapsed in 1947, owing to practical difficulties encountered in the enforcement of the details of the regulation amongst which were (1) lack of preventive staff over a long coast line and (2) lack of similar legislation in adjacent States.

INDUSTRY.

Sardine as Food.

As oil sardines, like others of the clupeoid group, are subject to easy spoilage, only limited quantities are sold fresh for consumption. In Tanur on the Malabar Coast the fresh fish are packed with crushed ice in dealwood boxes and despatched to the bigger towns like Madras, Coimbatore, Bangalore and Trichy. Most of the fish, however, is cured with salt in proportions ranging from 6:1 and 9:1 and sun-dried. The Ratnagiri method of wet curing is practised in Kanara by using salt in the proportion of 3:1.

The following chemical composition of oil sardine has been recorded by Chari (1948):—

Edible portion	..	..	70%
Protein	..	..	19.57%
H ₂ O	..	..	76.49%
Ash	..	..	1.79%
P ₂ O ₅	..	..	0.79%
CaO	..	..	0.47%
Iron	..	..	6.09 mg. per 100 gm.
Fat ¹	..	..	2.03%

Sardines were canned successfully by a French canner, M. de Josselin, at Mahe for many years before the establishment in 1911 of a State cannery at Calicut to demonstrate the possibility of producing a quality canned product in India comparable to the imported varieties. The removal of this cannery in 1914 to Chaliyam at the mouth of the Beypore river facilitated supplies of fresh sardines and mackerel from the sea soon after capture. The preservation of fish in sardine oil, curry, tomato and mustard sauces was successfully tried for packing purposes and the products were in great demand both in and outside India; samples exhibited at the Wembley Exhibition, London, in 1924 received commendations but unfortunately many technical and practical difficulties encountered in post-war years resulted in the closing of the factory in 1933.

Sardine Oil and Guano.

A crude and primitive method of extraction of oil was in vogue on the Malabar Coast for many years. The sardines were treated with boiling water in an old canoe and left in the open sun to putrefy until the oil exuded out of the body of the fish was skimmed off. A slight improvement on this method was to allow the oil to collect in one half of the boat separated from the putrefying fish by a perforated iron sheet. By this method, not only was some residual oil left unextracted but the quality also suffered greatly.

The low grade fertilizer that was also produced by allowing the surplus fish to rot and dry on the beach was used to manure tobacco-fields but the manure lacked the valuable nitrogen and phosphate contents while the contained oil, which is injurious to the crop, was also lost.

Nicholson in 1908 introduced an improved method by which the sardines were thoroughly boiled in cauldrons over an open fire, and the resulting oil ladled out into buckets containing cold water and finally washed and dehydrated. The boiled

¹ The fat content is known to vary up to 15% depending on the size, sex and season.

fish were put in coir-mat bags and pressed in the indigenous screw-presses. The second grade oil thus pressed out was marketed separately or mixed with the former to form the industrial sardine oils. The residue in the bags was dehydrated by sun-drying to form the guano. A merchant of Cannanore adopted this method producing a brown oil and guano of good manurial value. His success and the improvements since made by the Madras Fisheries Department led to the opening of a number of small factories on the Malabar and South Kanara Coasts reaching the peak of 647 factories in 1922-23. The output of guano and oil for the year showed record figures of 8,96,000 maunds and 3,36,000 maunds respectively. The quantity of oil sardines used for this purpose must have been, on a modest estimate, in the neighbourhood of 44,80,000 maunds. This estimate does not take into account the quantities cured in yards, beach-dried as manure, or consumed as fresh fish. It is not difficult to imagine the magnitude of the shoals of oil sardines which should have appeared in the inshore waters throughout the Coast. The lure of high prices led to malpractices in manufacture which brought down the trade with Europe. In later years, this fall in trade coupled with the diminution in numbers of sardines helped to reduce the number of oil and guano factories, but this reduction could not cope with the next unexpected bumper crop of sardines in 1933-34, when only 301 factories were working, producing 2,80,000 maunds of guano and 64,960 maunds of oil. The disastrous failure of the fishery which followed the 1941-42 season resulted in reducing still further the number of factories in operation to 8 in 1946-47 and to zero in 1948-49.

The crude oil extracted in the earlier years of plenitude was used locally as a preservative for boats against weathering and ship-worm attacks. Two grades of refined oil were later obtained, of which the first grade yellow oil was used in the leather industry and in arsenals, and the second grade brown oil (1) in the jute and steel industries, (2) as lubricants, and (3) as the base for good quality insecticides. The refined sardine oil was found to compare very well with the Menhaden or the Japanese sardine oil as may be seen from the following (Nicholson, 1922):—

Oil.	Specific gravity.	Saponification value.	Iodine value.	Acid value.
Menhaden oil	0.931	193	160	7
Japanese sardine oil ..	0.933	195	181-187	10-34
Malabar sardine oil ..	0.88	196	156	3-9 } 12-53 }

Although sardine oil has a vitamin A content of 25% of that of cod-liver oil, it was observed to deteriorate rapidly under storage. For well over a century the bulk of the exports was to Great Britain, Germany, Turkey and other countries.

The high nitrogen and phosphate contents of fish guano have made it a valuable manure for cash crops and plantations. The difference in the composition between the crude beach-dried manure and the improved guano may be seen from the accompanying table (Nicholson, 1922):—

			Beach-dried manure.	Improved guano.
			%	%
Water .. ..	..	..	15	9.77
Nitrogen .. ..	..	..	6.8	8.31
Phosphoric acid ..	..	..	5.3	8.82
Potash .. ..	..	..	0.7	0.40
Total organic matter ..	..	..	60	66.28

The improved guano has been in great demand in coffee, tea, coconut, sugarcane and tobacco plantations and exported mostly to Colombo and to Japan.

Sardine Meal.

Sardine fish meal specially prepared in factories after the removal of the oil was in great demand with European live-stock owners. Its composition is as follows (Chari and Pai, 1948):—

					%
Moisture	..	..	..	..	9.68
Protein	..	..	..	..	65.27
Fat	..	..	..	..	9.54
Ash	..	..	..	..	14.77
P ₂ O ₅	..	..	..	..	5.79
CaO	..	..	..	..	6.01
NaCl	..	..	..	..	0.32
Insolubles	..	..	..	..	1.78
Unidentified	..	..	..	..	0.75

BIOLOGY.

The oil sardine, easily distinguished from other Indian sardines by its relatively long head and golden sheen, grows to a maximum size of 22-23 cm., the commercial size ranging from 12-20 cm. Its food consists of plankton with phytoplankton predominating. The spawning season extends roughly from August to November. The fish appears to be a prolific breeder judging from the large number of pelagic eggs (estimated at 75,000) liberated.

The oil sardines occur off the Coasts of Arabia and Iran (from collections received), Pakistan, India, Ceylon, Java and Bali Straits (Day, 1889 and Weber and Beaufort, 1913). The range of distribution in India extends from Kathiawar in the North, down the West Coast of India and rarely to the Coromandel and the Ganjam Coasts (Hornell and Nayudu, 1924) but shoaling in large numbers is known so far only on the Kanara and Malabar Coasts.

The oil sardine and the mackerel, which provide the largest fishery on the West Coast and contribute much to the welfare of the people, have attracted the attention of fishery workers in India for many years, more particularly to their fluctuations in occurrence. According to Hornell and Nayudu (1924) there are no local races among the oil sardines of Malabar and South Kanara, which attain sexual maturity when they are 15 cm. long and one year old. They move offshore prior to spawning from June to August which seems to result in high female mortality and the young enter shallow inshore waters in August and September to feed on the abundant plankton characteristic of the post-monsoon season. The fat of the oil sardine is apparently accumulated during September to December. The probable life span of sardine based on scale studies is two and a half years but growth appears to be slow in the second year. Devanesan (1943) confirmed some of Hornell and Nayudu's observations and contributed towards the knowledge relating to spawning and age determination. Nair's (1949) study of the growth rings on the otoliths makes it probable that the oil sardines attain maturity when they are two years old and 15 cm. long, and have a life span of three to four years. Chidambaram's (1950) close examination of the recorded data of measurements of oil sardines during the period 1936-43 lends support to Nair's findings. These data also reveal that indiscriminate fishing of immature sardines results in the proportionate reduction in the number of spawners in the fishery in succeeding years. The records also reveal that (1) small-sized sardines preponderate in years of abundance, (2) there is a correlation between the surface temperature and specific gravity of sea water and availability of food with

the movements and spawning of oil sardines and survival of the young, and (3) investigation on the occurrence of the sardines in the offshore regions is urgently necessary to appraise the causes of fluctuations in their abundance.

CONCLUSION.

It will be noticed that the available statistics furnished in this paper show an irregular fluctuation in abundance of oil sardines at intervals ranging between 2 to 6 years, between 1907 and 1942. It is also seen that the small-sized immature sardines have contributed largely to the success of the fishery in the years of abundance, viz. 1912-13, 1913-14, 1919-20 and 1922-23, and this has found corroboration in the fishery of 1933-34 and the following years.¹ It is of interest to record here that the recovery of the fishery on the West Coast of India in the current year is due mainly to the dominance of immature fish, 10 to 13 cm. long. As small sardines seem to contribute generally to the success of the fishery, the effect of indiscriminate fishing of immature sardines will be seen only in the succeeding years when fewer mature spawners will be available in the fishery. Apart from this factor of reduction in the number of spawners, there are other adverse factors influencing the rate of survival and recruitment to the stock such as unsuitable hydrological conditions, low survival rate of the larvae, and lack of the necessary food for the fry and juvenile sardines. The obvious remedy to combat the difficulties enumerated above is to introduce cautious, practicable and enforceable regulations to diminish the inroads made on immature sardines in the good fishing years, and to study simultaneously the effect of the enforcement on the biological and socio-economic factors.

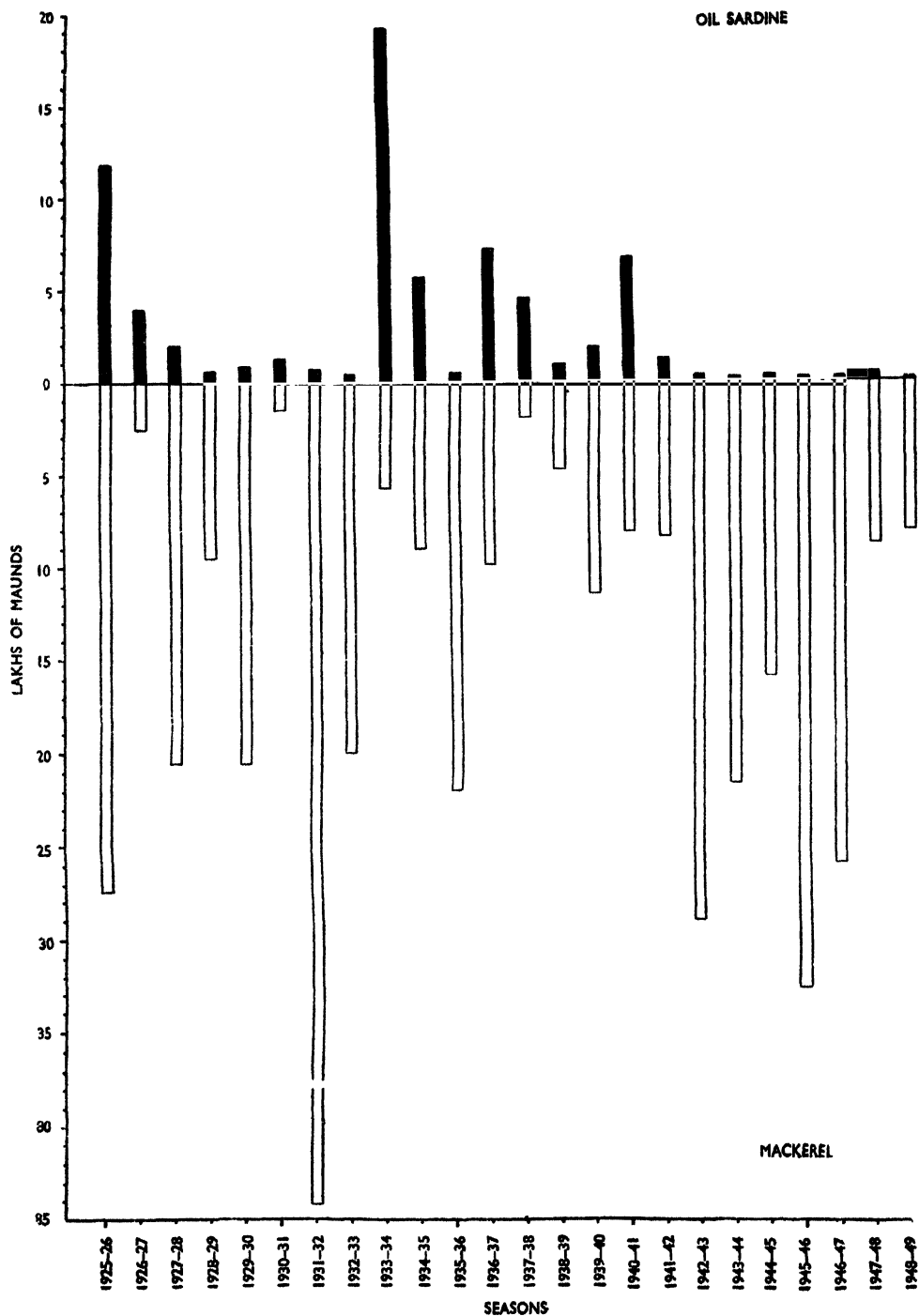
It is also necessary to study the influence of the fluctuating nature of the sardine fishery on other fisheries in the region. Hornell (1910) saw a connection between the marked diminution of sardine and the abundance of mackerel as in 1901, and drew attention to the fact that the sardines and mackerel were 'scarcely ever abundant in the same year; a good year for the one is usually coincident with an unsuccessful fishery for the other'. Such a relationship may be observed in the accompanying histogram based on the records of landings available for the period 1925-26 to 1948-49. Similar related inverse trends of variations in the catches of sardine and mackerel were observed till 1941-42 from which year onwards the oil sardine fishery gradually declined to its lowest ebb in 1946-47 from which a recovery is again noticeable, as for instance, in the exceptional abundance of oil sardines in the Karwar waters which have, for many years, been an area for mackerels alone, in the post-monsoon season of 1949-50.

In this connection it may be of interest to compare the recorded data of the sardine fisheries in other parts of the world. The sardine fishery of the Pacific Coast of North America extending from British Columbia to Mexico, accounted in 1936-37 for 7,90,000 tons, but the decline started after 1944 resulting in a financial crisis in the industry. In California the production dropped down to 1,24,000 tons in 1947-48. The 'worst sardine fishing year in living memory' was recorded in the Gulf of Aden for the season 1948-49.² In the Japanese and Korean waters there has been a marked decline in the availability of sardines since 1941 from which there has been no recovery till 1949; and it is stated³ that the present increased landings of fish in Japan and the Pacific Coast of U.S.A. are mainly due to the appearance of sardines. It is of interest to record the simultaneous decline and recovery of the world sardine fishery as seen in recent reports on this fishery in California, Japan and India, and it is likely that more or less similar factors affect the fishery of sardines as a whole in the Pacific and Indian Oceans.

¹ Administration Reports of the Madras Fisheries Department.

² 'Science's part in Colonial Progress'. *The Fishing News*, 37, No. 1895, 11.

³ *F.A.O. Fisheries Bulletin*, 3, No. 1, Jan.-Feb., 1950, 4.



Histogram showing the relationship between the annual landings of the oil sardine and those of the mackerel in the South Kanara and Malabar Coasts from 1925-26 to 1948-49.

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Table showing the number of oil and guano factories and the quantities of oil and guano produced in South Kanara and Malabar from 1906 to 1949.

Years.	No. of factories. ¹	Oil in mds.	Guano in mds.
1906-07	..	..	1,60,216
1907-08	..	..	3,75,212
1908-09	1	..	..
1909-10	3	..	..
1910-11	9	..	5,264
1911-12	45	..	7,476
1912-13	45	..	52,416
1913-14	211	42,308	1,32,328
1914-15	211	..	..
1915-16	250	14	70
1916-17	..	..	..
1917-18	..	..	..
1918-19	358	..	..
1919-20	563	..	67,200
1920-21	646	..	42,000
1921-22	542	..	28,000
1922-23	647	3,36,000	8,96,000
1923-24	440	2,03,000	6,30,000
1924-25	515	56,000	1,12,000
1925-26	463	1,39,440	2,75,800
1926-27	504	17,920	58,800
1927-28	470	5,600	23,800
1928-29	282	1,960	30,800
1929-30	325	672	6,244
1930-31	236	1,820	4,396
1931-32	32	364	3,920
1932-33	96	15	560
1933-34	301	64,960	2,80,000
1934-35	..	..	..
1935-36	4	182	700
1936-37	103	12,572	62,580
1937-38	145	11,676	43,820
1938-39	56	1,022	7,616
1939-40	69	2,744	11,340
1940-41	203	12,628	57,568
1941-42	180	504	2,716
1942-43	186	140	1,456
1943-44	188	546	672
1944-45	178	298	546
1945-46	178	1	448
1946-47	166	..	896
1947-48	162	..	..
1948-49	162	..	..

¹ The figures show the number of factories in existence including those in operation.

Table showing the estimated landings of oil sardines and mackerels in South Kanara and Malabar from 1925 to 1949.

Years.	Oil sardines in mds.	Mackerels in mds.
1925-26	11,92,449	27,41,541
1926-27	3,96,647	2,60,145
1927-28	1,93,012	20,73,090
1928-29	48,433	9,70,329
1929-30	73,778	20,90,603
1930-31	1,15,872	1,49,909
1931-32	58,553	84,26,860
1932-33	30,113	20,09,661
1933-34	19,23,593	5,97,757
1934-35	5,58,210	9,11,072
1935-36	40,149	22,35,427
1936-37	7,27,726	10,07,046
1937-38	4,56,037	2,10,680
1938-39	91,449	4,88,702
1939-40	1,89,964	11,60,482
1940-41	6,77,009	8,23,934
1941-42	1,19,231	8,63,722
1942-43	24,038	29,46,567
1943-44	11,858	21,85,796
1944-45	17,595	16,08,870
1945-46	476	33,06,709
1946-47	237	26,29,645
1947-48	31,913	8,84,412
1948-49	7,789	8,13,265

Table showing the landings of oil sardines in South Kanara and Malabar for the year 1949-50.

Months.	South Kanara.	Malabar.
	Maunds.	Maunds.
July, 1949 .. ..	..	..
August, 1949 .. ..	..	..
September, 1949 .. ..	..	100
October, 1949 .. ..	..	695
November, 1949 .. ..	..	19,115
December, 1949	11,676	23,017
January, 1950	3,516	16,118
February, 1950	307	7,154
March, 1950	574	6,375
April, 1950	10	1,765
May, 1950	110
June, 1950	295
Total	16,083	74,744
Grand Total	90,827	

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STUDIES IN CROP PHYSIOLOGY.

PHYSIOLOGICAL RÔLE OF NITROGEN IN GROWTH AND METABOLISM OF SUGARCANE.

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(Communicated by Prof. G. P. Majumdar, F.N.I.)

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INTRODUCTION.

Nitrogen is known to affect growth and metabolism of crops in many ways. Applied to cane it improves vegetative activity, increases reducing sugars, total and alcohol soluble nitrogen, promotes succulence and electrical conductivity of juice but produces no difference either in polysaccharides or in pH of juice; sucrose is, however, lowered. Absorption of ash constituents is greatly affected with consequent changes in hydration state, enzymic efficiency, concentration of soluble substances and elaboration of carbohydrates (Das, 1936). That nitrogen increases height, leaf number and girth of stem, augments accumulation of dry matter, improves assimilation rate of leaves at all stages and respiration only during early periods, induces high yield and low juice purity have also been pointed out earlier (Singh, 1941*a*). Its deficiency decreases height and girth, reduces starch and total carbohydrates in dry matter, diminishes assimilation rate and chlorophyll content of leaves and decreases yield in pot cultures. In high nitrogen cultures on the contrary, improvement in height and girth, reduction in sucrose, purity and °Brix, diminution in respiration rate but increase in yield and glucose are recorded (Singh, 1941*b*). Further deficiency shows harmful effects on shoot growth primarily but improves juice quality partially (Lal and Pathak, 1948). Its effect on photosynthesis is greatly determined by presence or absence of other nutrients (Singh and Lal, 1940). Indications for overcoming deficiency effects are also observed when boron is available in small doses in deficient medium (Lal and Srivastava, 1949). Its response varies slightly with time of application of nitrogen (Lal, Srivastava and Pathak, 1948), form of nitrogenous fertilisers and ratio and combination in which this ingredient is available (Singh, 1942), and soil and climatic conditions under which investigations are carried out. Lower doses are known to improve bud growth and tillering while higher ones increase leaf size, succulence and total and soluble nitrogen in extract. Higher levels reduce phosphate and sucrose in sap but do not necessarily decrease yield (Rege and Sannabhadti, 1944).

It is the intention to marshal some of the relevant facts on nitrogen nutrition recorded in these laboratories to elucidate (i) the manner in which this ingredient brings about alterations in growth, yield and juice quality and (ii) to discuss the role of nitrogen in various processes of growth and metabolism. This analysis is based on manifold responses of this ingredient noted during the years 1937-1949 on (i) vegetative characters, e.g. height, tillering, leaf number and size, girth and size of internodes; (ii) physiological characters, e.g. dry weight, respiration and assimilation rate, chlorophyll content, element composition and yield; and (iii) juice characters and carbohydrate fractions. Relevant data and graphs have been presented. For other details reference may be made to the original source from which these informations have been secured.

EXPERIMENTAL RESULTS AND DISCUSSION.

A. *Response of nitrogen on vegetative characters.*

Irrespective of treatments and nitrogen deficiency, height, girth and leaf size all improve with advance in age up to August; thereafter age effects are less characteristic (Fig. 1). Tillers, exposed internodes and leaf number attain highest values in July subsequent to which decline in tillering and leaf number ensues. Exposed internodes show slight rising tendency towards end of season. Slight variations in growth are, however, discernible in deficiency cultures. Evidences further indicate that leaf width, leaf length, tillering and height are markedly higher in optimum nitrogen canes (Fig. 2). Deficiency on the contrary, lowers these characters at all stages. Compared with no manure culture, partial deficient plants show better leaf size but no marked difference in tillers and leaf number are noted. Nitrogen deficiency thus reduces leaf size but not necessarily leaf number. Girth too is reduced in deficient plants.

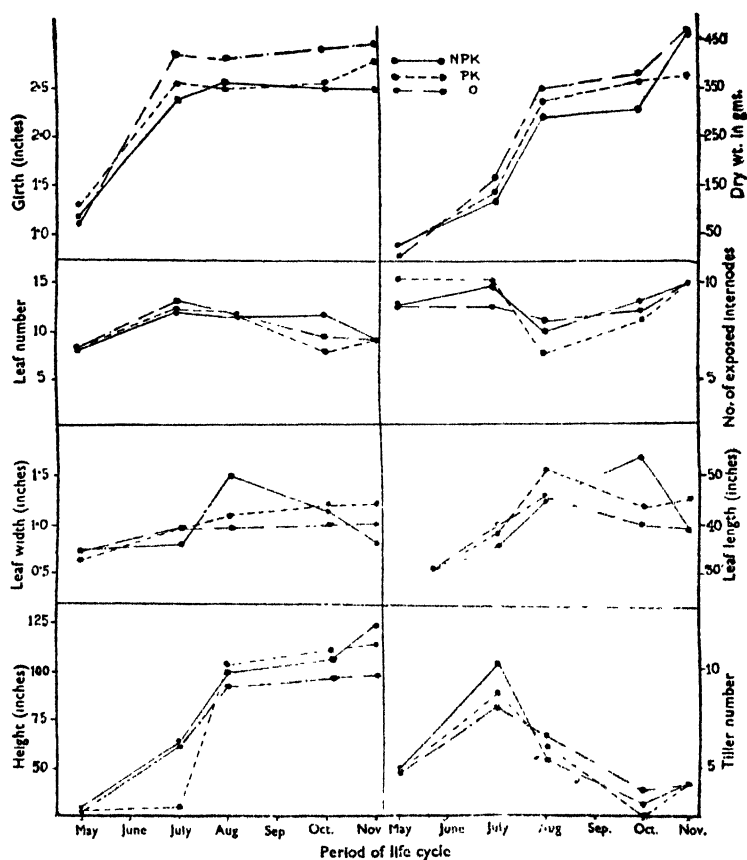


FIG. 1.—Growth characters of sugarcane in relation to age and nutrition.

[Drawn from the data of Singh *et al.* (1941).]

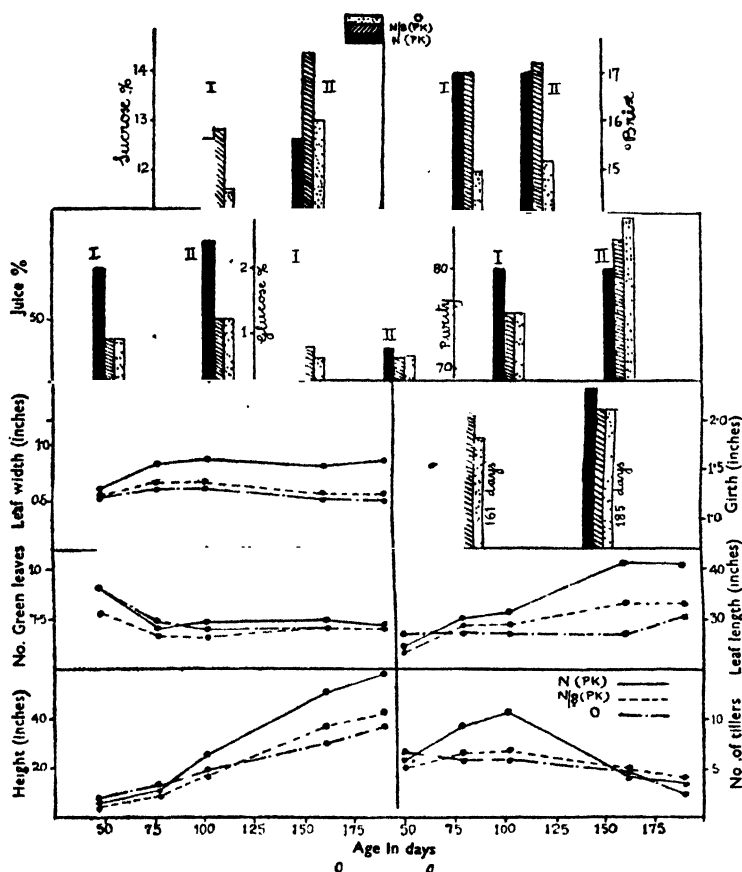


FIG. 2.—Developmental and Juice characters of sugarcane as affected by age and nutrition.

[Redrawn from data of Lal and Pathak (1948).]

Under adequate phosphorus and potassium supply, vegetative characters are markedly affected by nitrogen deficiency (Fig. 3). Nitrogen fed canes show maximum height, tillering, leaf number and fresh weight of plant. The greater the degree of nitrogen deficiency relative to optimum nitrogen levels, the more is the reduction in these characters. No nitrogen cultures containing P and K only, show least development of these characters.

Nitrogen sufficiency also shows marked effects on vegetative characters. Height and leaf length increase with doubling of dose beyond 150 lbs. N. Sufficiency at 2N level is also helpful on girth; tillering remains unaffected up to 4N level (Fig. 4). Further increase to 8N level lowers tillering but girth is unaffected. In contrast to these, lack of nitrogen, under otherwise similar conditions reduces tillers, girth, height and leaf length. In another work again, nitrogen deficiency has been found to lower length of shoot, leaf number and tillers at all stages (Fig. 5). Further, relative nitrogen deficiency compared to optimal dressing, lowers height, reductions being more severe under greater nitrogen deficiency. Tillering and leaf size improve markedly when plants are well fed with nitrogen. Partial deficiency of this ingredient is better than high deficiency in so far as girth is concerned. Differences in other directions are less characteristic (Table 1). In sand nutrient

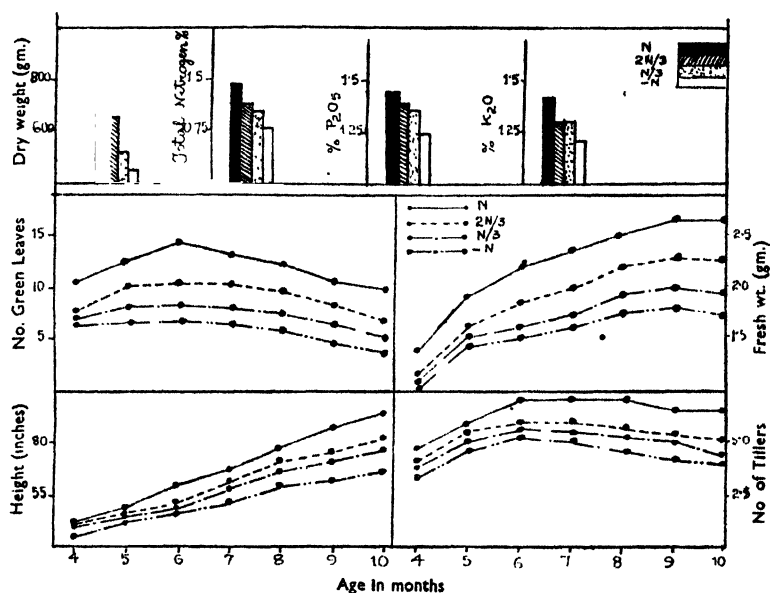


FIG. 3.—Growth characters and ash constituents in dry matter in relations to age and nutrition.

[Drawn from data of Singh *et al.* (1942).]

cultures, lack of nitrogen also significantly lowers height, leaf number, leaf size, number and length of exposed internodes, girth and length of stripped cane (Table 2). Tillering is less markedly affected.

These results portray the deleterious effect of nitrogen starvation on vegetative growth in height, tillering and leaf size. Number of green leaves at least at some stages is also reduced with increasing nitrogen starvation. Girth is similarly lowered in minus nitrogen cultures in some of these experiments. Irrespective of the medium of growth, harm done to the plant is found proportional to a certain extent to the level of nitrogen starvation in the culture medium. Nitrogen starved plants are as a rule, pale and stunted in size with thin, narrow and short leaves. Yellowish green colour is uniformly spread throughout the lamina. Nitrogen fed plants on the contrary, show greater depth of leaf colour, larger leaf surface and rapid increase in shoot number (Singh *et al.*, 1942).

B. Responses of nitrogen on physiological characters.

Respiration:—Decrease in respiration of leaves in general, is noted with age. This is characteristic in no-manure cultures (Fig. 6). Under optimum doses rise in respiration is noted up to 135 days followed by a fall and a slight rise towards the end. At 45–90 days and also at 180 days, respiration of nitrogen deficient plants is higher than that in optimum nitrogen culture. At other stages, respiration of starved plants is usually lower. In another experiment, leaf respiration in normal nitrogen culture has also been found to be high (Fig. 4). Deficiency or excess of this ingredient shows deleterious effect.

Photosynthesis:—Apparent assimilation of leaves shows two high values at 45 and 225 days in fully manured plants (Fig. 6). Nitrogen-deficient plants also exhibit peak values at 135 and 225 days. Deficient supply of nitrogen in general, lowers apparent assimilation. Real photosynthesis too shows two peak values first between

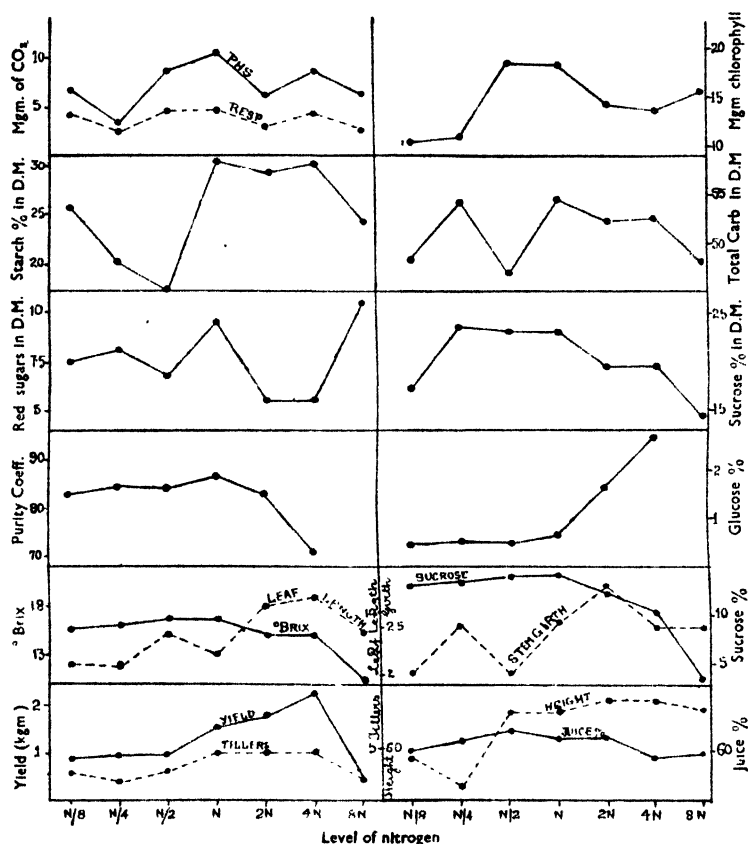


FIG. 4.—Plant characters in relation to nitrogen levels
[Redrawn from data of Singh (1941b).]

90–135 days and second at 225 days. Nitrogen deficient plants show lower photosynthesis but are better than no-manure cultures. In sand fertiliser cultures (Fig. 4) standard dose of nitrogen (150 lbs.) proves to be better than all other lower or higher levels. Partial deficiency too is slightly better than sufficiency at two times the standard dose of nitrogen.

Chlorophyll:—Chlorophyll content of leaves is also lowered by nitrogen deficiency (Fig. 6). In sand fertiliser cultures, partial deficiency ($N/2$) has been found to be better than excessive nitrogen feeding at $2N$ level. At still higher levels of sufficiency excessive nitrogen, however, proves better than extremes of deficiency at $N/4$ and $N/8$ levels.

Fresh and dry weight and yield:—Optimum nitrogen cultures prove definitely superior to nitrogen deficient cultures on fresh and dry weight of plants (Fig. 3). In general, the greater the deficiency of nitrogen the lower is the dry weight at all stages of growth. Similar results have been recorded in sand nutrient cultures where complete nutrient cultures are found better than plants raised in deficient medium (Table 3). Yield of stripped cane is always higher in sufficiency cultures as compared with deficiency cultures (Fig. 4).

Intake of elements:—Nitrogen absorbed shows proportional decrease with degree of nitrogen deficiency (Fig. 3). Optimum nitrogen cultures show highest nitrogen

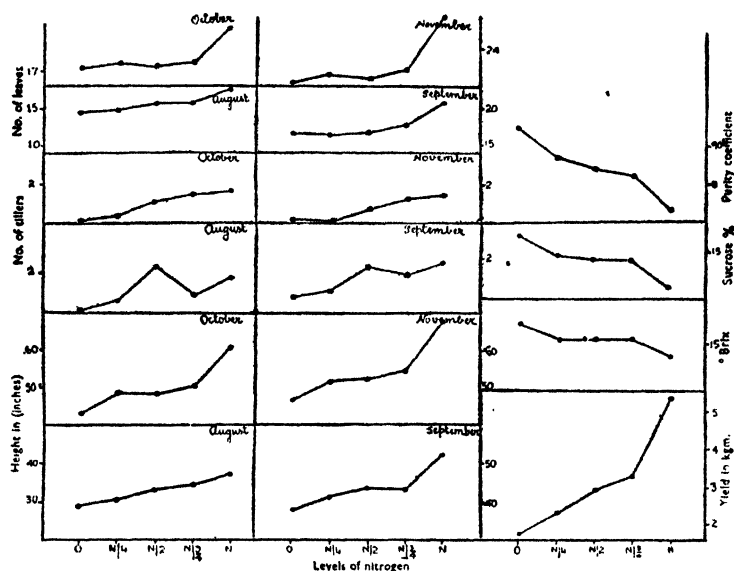


FIG. 5.—Growth and Juice characters of sugarcane in relation to nitrogen levels.

[Redrawn from data of Lal and Pathak (1948).]

in dry matter. Decline in nitrogen intake with increasing deficiency is more characteristic towards early stages. In nutrient cultures (Table 3) again nitrogen intake is noted to be higher in complete nutrition than in deficiency medium. Nitrogen deficiency lowers percentage of total nitrogen in dry matter.

Amount of phosphorus and potassium is also reduced under nitrogen deficiency more during early stages than during later periods (Fig. 3). Percentage of phosphorus is also reduced in nitrogen deficiency cultures. Potassium is affected only slightly during early stages when nitrogen deficiency is found to lower its percentage (Table 3).

Evidences on physiological characters indicate that in general nitrogen deficiency lowers photosynthetic rate of leaves at all stages. This is associated with low chlorophyll, poor dry matter, reduction in percentage of phosphorus and nitrogen in dry matter and low yield. Poor growth is therefore due to lower physiological efficiency of plant as a whole in the matter of absorption of raw materials both from soil and air.

C. Response of nitrogen on composition of plant.

Nitrogen deficiency invariably raises percentage of sucrose and total solids in cane juice (Fig. 7). Glucose and purity are less affected. In sand cultures, differences between nitrogen deficiency and sufficiency are more evident. Deficiency raises °Brix, sucrose and purity coefficient while glucose is reduced (Fig. 4). Increasing levels of nitrogen deficiency do not materially alter these characters while increasing sufficiency proves deleterious on sucrose, °Brix and purity. Glucose in the latter case is markedly increased. Moderate nitrogen deficiency between $N/2$ and $N/4$ levels raises sucrose in dry matter. Majority of deficiency or sufficiency cultures lower reducing sugars; in none of these cases the level reaches that attained in normal nitrogen cultures. Deficiency also reduces starch percentage while sufficiency at 2 or 4N levels improves its content. Total carbohydrate in dry matter are reduced in both deficiency and sufficiency cultures below that of the normal

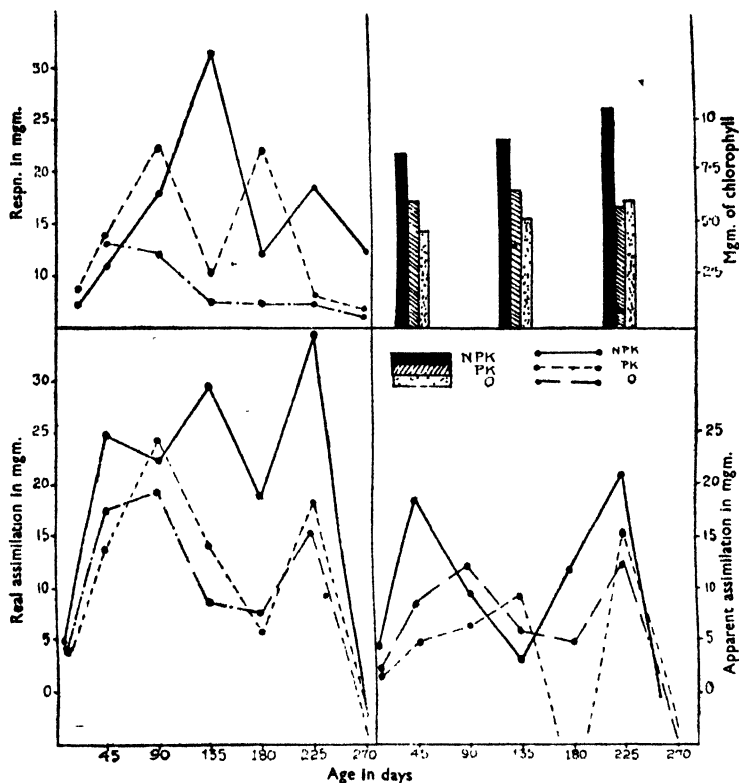


FIG. 6.—Real assimilation, respiration and chlorophyll content of leaves in relation to age and nitrogen.
[Redrawn from data of Singh (1941a).]

nitrogen plants. In another investigation (Fig. 5) nitrogen deficiency again has been noted to raise sucrose, °Brix and purity coefficient as against the yield which is lowered consistently with increasing deficiency. Further total carbohydrates, starch sucrose and reducing sugars are all reduced in nitrogen deficiency cultures (Table 4).

On carbohydrate content of tissues, nitrogen starvation shows two types of responses. Sucrose and total solids in juice and reducing sugars and sucrose in dry matter are increased while starch is reduced. On purity, deficiency shows useful effects. Responses have been found to be largely determined by the relative deficiency or sufficiency of nitrogen in culture medium.

D. Age and nutrient effects on nitrogen response.

Evidences recorded in different directions show that age effect is very predominant in controlling the full exposition of fertiliser response. Nitrogen feeding no doubt varies the magnitude of several physiological, vegetative and compositional characters but fails to materially alter the general trend of variations so characteristically noted with advance in age. In the juvenile phase (45–135 days) nitrogen starvation exhibits marked effects on intake of elements and largely regulates full exposition of such physiological activities as assimilation and respiration rate of leaves. In the adolescent stage (135–235 days) nitrogen feeding influences development of tillers, leaf number, leaf size, girth and height of cane. Finally in the

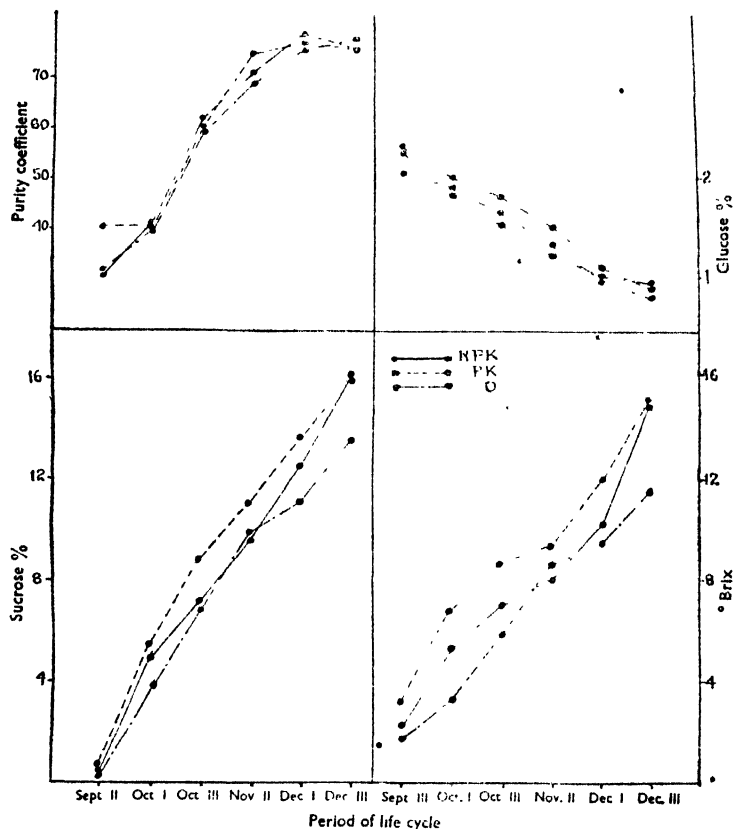


FIG. 7. Juice characters of sugarcane as affected by age and nutrition.
[Redrawn from data of Singh *et al.* (1942).]

pre-senescent period nitrogen affects composition and quality of juice. Its effects are thus characteristically observed throughout the life cycle of sugarcane. The nature of response differs as indicated with the developmental stage of plant.

Efficiency of absorbed nitrogen in dry matter accumulation is found to be affected by nitrogen starvation (Singh, 1942). Between 4–7 months this efficiency is highest under extreme nitrogen deficiency and diminishes with increasing nitrogen supply. Under lower nitrogen levels, all the absorbed nitrogen is utilised for various metabolic and growth activities whereas in high nitrogen cultures part of absorbed nitrogen remains unutilised exhibiting state of luxury consumption for the ingredient. That medium nitrogen feeding results in greater dry matter accumulation has also been recorded by Das (1936) and experience is not uncommon of obtaining higher increments in yield with lower levels of nitrogen.

Data on absorption of nutrients further point out (Table 3) that nitrogen intake is primarily a function of age and secondly the nutrient status of medium. Differential feeding not only affects percentage composition of nitrogen, but induces alterations in potassium and phosphorus content as well. Increased nitrogen uptake is accompanied by greater phosphorus and potassium absorption but increases in the latter two elements are hardly commensurate with the demands set up by state of luxury consumption of nitrogen in plants. Compositional changes in carbohydrate fractions also ensue (Figs. 4, 5). These clearly emphasise the dual nature of influence

of form of absorbed ion on metabolism. In the first instance, there is the absorption of ion itself with marked effects on the absorption and accumulation of other ions; secondly, there are the effects of concentration and form of ions within the plant upon composition and growth. Absorption of ions, accumulation of ash constituents and elaboration of carbohydrates are thus interrelated.

E. *Nature of nitrogen response in sugarcane.*

Nitrogen nutrition of sugarcane appears in the light of these researches to be a highly complicated process. Difficulty arising out of a large number of edaphic variables influencing availability of nitrogenous fertilisers in soil, renders thorough analysis of the problem difficult. On basis of evidences so far accumulated a vivid picture of nitrogen response may, however, be visualised. Nitrogen applied to soil primarily affects solution phase in soil. Quantity of nitrogen absorbed depends upon form of nitrogen ion, its relative concentration and also upon changes induced by different ions on the permeability of absorbing membrane. Inside the roots, changes in nitrogen concentration are accompanied by alterations in relative rate of absorption of other ingredients, variation in hydration state, changes in efficiency of enzyme system and elaboration of various nitrogenous bodies. Nitrogen in inorganic or organic form is translocated to leafy regions where complex changes in nitrogen fractions take place. The first visible effect of high nitrogen feeding is noted in leaves which turn deep green and show high capacity of photosynthesis. Leaf surface increases, changes in growth of shoot and other organs ensue as fresh supply of carbohydrates and efficient metabolism of absorbed nitrogen are assured. High respiratory activity of plants during early stages, however, does not permit rapid accumulation of materials with the result that sugarcane plant exhibits increase in size and form more than increase in dry weight. Materials formed and energy liberated are utilised to maximum advantage in the development of various organs.

By the end of Juvenile phase, formation of various organs slows down, respiratory activity declines resulting in surplus of materials which increases the dry weight. Properly nitrogen fed plants invariably show better performance during juvenile phase in all activities and there is every reason to believe that any deficiency during this period not only affects the early developmental activities but also greatly hampers the future development of plant. With inducement of greater vegetative vigour, large surpluses of carbohydrate and other materials are likely to be available towards the beginning of adolescent stage. Larger number of tillers are formed as a result of these surpluses. The survival of these shoots depends upon (i) extent to which absorbed nitrogen keeps alive all the metabolic activities of the shoot, and (ii) upon the surpluses left over for further development and independent establishment of new shoots. If nitrogen absorbed is still commensurate with growth requirement of this phase of high tillering mortality of shoots is low. If it falls short of the requirement, shoots become weaklings due to starvation and ultimately die out. It is, therefore, imperative to check vegetative vigour of plants during juvenile phase beyond a certain critical limit to enable sufficient nitrogenous materials in the plant body to be left over for future use during adolescence. External feeding with nitrogen is of little avail as plant's efficiency to absorb nutrients is very much lowered at this stage. Balanced growth during juvenile and adolescent phases, is absolutely essential for utilisation of conditions of growth and nutrition to maximum advantage. Under field conditions this is difficult to be achieved. Due to constant variations of growth factors, a nutrient may be entirely or partially limiting at one or more stages and yet act as surplus at other periods of life cycle. Nutritional responses are in consequences greatly marred by the effects of changing environment.

During pre-senescence when peak values are attained in dry matter and sucrose content in juice and when plant's activities are diverted towards accumulation of sugars, nitrogen seems to have a less important rôle. With cessation of all vegetative

activity and reduction in efficiency of leaves to manufacture carbohydrates following disintegration of chloroplasts and fall in chlorophyll content, the plant exhibits a general breakdown of all constructive and tissue building activities. With desiccation of tissues, interconversion of carbohydrates and other materials takes place rapidly with enzymes playing a more important rôle than nitrogen in this phase of the life cycle. While this may be the normal state of affairs, in excessive nitrogen cultures, absorbed nitrogen may still be in high concentrations with the result that vegetative activities may be prolonged resulting in formation of fresh shoots. Some of the upgrade processes involving carbohydrates and their utilisation in the initiation and development of new shoots seem to be responsible for the low sucrose in cane in all high nitrogen cultures. Significance of changes involved and rôle of nitrogen during this phase is less clearly understood so far. Further light on nitrogen metabolism of cane would appear elsewhere.

SUMMARY.

The paper deals with effects of nitrogen deficiency and sufficiency on growth and metabolism of sugarcane based on the results of investigations conducted during 1937-1948 under conditions of soil and nutrient cultures. These portray the manner in which nitrogen feeding affects growth of sugarcane.

Nitrogen deficiency induces stunted growth, poor development and reduced size of leaves, poor tillering, smaller girth, and reduced vegetative activity. It also lowers photosynthesis and chlorophyll content. Intake of nitrogen is reduced. Reductions in phosphorus and potassium content are occasionally evident, particularly during early stages. Poor growth in general is due to low physiological efficiency of plant as a whole in matter of absorption of raw materials from soil and air. Partial nitrogen deficiency is slightly helpful on sucrose and juice purity.

Nitrogen starvation does not materially alter the general trend of variations in growth characters with age, though specific nitrogen deficiency symptoms are noted at different stages. During early juvenile stage, withholding nitrogen supply reduces intake of elements and checks development of assimilating system. In adolescence, all vegetative characters are poorly developed. During pre-senescence partial deficiency proves helpful on sucrose and juice purity while excessive nitrogen proves deleterious.

Efficiency of absorbed nitrogen in dry matter accumulation increases with age and nitrogen deficiency. Nitrogen absorbed from partial deficient cultures is entirely utilised for metabolic activities; that absorbed in larger quantity from excessive nitrogen medium remains in a state of luxury consumption. Emphasis is laid on dual nature of the influence of form of absorbed ion in the absorption and accumulation of other ions and in bringing about changes in growth and composition of plant.

Suggestions have been put forward to indicate the manner in which nitrogen affects growth performance during juvenile, adolescent and pre-senescent stages of life cycle. Nature of nitrogen response has been discussed in its essential details with reference to the physiological needs during different periods.

TABLE 1.

*Mean difference in growth characters from the no-manure cultures.**

Characters.	N/3—0	2N/3—0	N—0
Height	9.06 ± 2.06†	11.33 ± 4.02†	18.20 ± 2.70†
Tillering	0.52 ± 0.45	1.27 ± 0.24†	0.57 ± 0.16†
Leaf length ..	5.50 ± 1.53†	11.07 ± 5.23†	10.90 ± 1.28†
Leaf width ..	0.10 ± 0.77	0.19 ± 1.12	0.25 ± 1.32
Leaf number ..	-0.57 ± 0.15†	-0.45 ± 0.23	0.52 ± 0.55
Exposed internodes ..	0.67 ± 0.37	0.42 ± 1.27	1.06 ± 0.28†
Girth	0.24 ± 0.05†	0.29 ± 0.07†	0.08 ± 0.06

* Calculated from the data of Singh *et al.* (1942).

† Indicates significant effects.

TABLE 2.

*Growth characters of sugarcane in sand nutrient cultures **

Characters.	Complete nutrition.	Nitrogen deficiency.	S.D. at 5%
Height	119.10	89.80	7.20
Tillering	1.69	1.00	1.30
Leaf number	17.12	12.87	1.07
Leaf length	61.20	45.90	5.40
Leaf width	1.52	0.81	0.07
Exposed internodes	6.62	3.81	1.13
Length of internode	4.72	4.06	0.41
Girth	1.87	1.46	0.16
Length of stripped cane	60.70	44.46	7.14

* From the data of Singh *et al.* (1942).

TABLE 3.

*Dry weight, nitrogen, phosphorus and potassium content of cane grown in complete nutrition and nitrogen deficiency.*Taken from the data of Singh *et al.* (1942).

Age in months.	Nitrogen (N)		Phosphorus (P_2O_5)		Potassium (K_2O)	
	Control.	Minus N.	Control.	Minus N.	Control.	Minus N.
1	1.81	1.61	1.72	1.41	5.11	4.31
6	0.70	0.47	0.50	0.51	0.86	0.88
9	0.57	0.19	0.42	0.33	0.73	0.76
	Dry weight of entire plant					
1	10.20	5.12				
6	380.10	76.30				
9	522.80	195.90				

TABLE 4.

*Carbohydrate fractions in dry matter of sugarcane at nine months.*Taken from the data of Singh *et al.* (1942).

Treatment.	Total Carbo- hydrate.	Starch.	Sucrose.	Reducing sugars.
Complete nutrition	59.6	30.1	24.2	5.3
Nitrogen deficiency	37.3	20.5	15.3	2.5

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THE ELASTIC PROPERTIES OF SINGLE JUTE FILAMENTS. II—CREEP & CREEP RECOVERY.

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1. INTRODUCTION.

The results of the study of Young's modulus by flexure, of a jute filament, have already been reported (Sen, 1948). The present study of the creep in jute and the recovery of the material from strain, is also confined to similar filaments. For the data recorded here, a simple device for direct measurement was employed. Experiments were very carefully performed to minimise adequately any effect of shock-vibration of the freely hanging filament especially when the load was added or removed. The work was done in a partially conditioned atmosphere. However, the changes in the relative humidity or temperature, during a particular experiment on a variety, were quite small; so it is considered that no worthwhile disturbance was caused in the observations. Large variation in humidity was noted in the case of some of the different experiments on different varieties. In the work on single filaments of jute it is likely that an individual under test should vary in cross-sectional thickness. But as the present measurements were concerned with only the overall effect, and as any creep effect must depend on the internal structural make-up of the filament only, it is expected that the possible outside irregularity of thickness of filament at different points of its length, is not likely to cause any serious error, especially when the stresses employed were too small to produce any noteworthy plastic flow even in the thinnest region. Use of any elaborate machine for measurement of the present kind was deliberately avoided, as such arrangement would be likely to mask the extremely small effects on jute by imposition of uncertain machine factors. (The extension of a jute filament at break is, on an average, hardly better than 2%.)

The creep and its recovery, which are but the visco-elastic properties of a material, are very important in the case of a textile fibre. These properties basically determine the dimensional stability of the product in relation to the stresses which operate during the manufacture of goods, as well as under the conditions of their utilisation, and in laundering.

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It is well known (Smith, 1944) that the elastic (and rheological) properties exhibited by a finished textile material, are largely derived from the similar properties of the component units, i.e. the single filaments, except in so far as the structural conditions of the material augment or modify the effects. For this reason, it is considered more logical to begin with the primary constituents of a finished textile material, in other words, the single filaments. These primary units of construction should naturally be quite free from the various other complexities likely to be imposed by the structure of the yarn and the fabric; and their simple properties therefore become amenable to easy experiments.

Apparently no literature seems to be in existence in respect of the delayed elastic properties, or creep, of jute filaments, although fairly extensive studies on rayon, nylon, silk, etc., have been recently made (Leaderman, 1943). Some results of preliminary nature obtained by the writer on jute filaments were discussed (Sen, 1947) some time ago. A more careful and detailed study is now under report.

The writer is indebted to Shri S. R. Guha, B.Sc., for carrying out the various experimental measurements. The work forms part of the fundamental investigations on jute carried out under the auspices of the Indian Central Jute Committee. The author is also indebted to Dr. P. B. Sarkar, D.Sc., F.N.I., Director, for encouragement in the matter of writing up of the paper for publication.

2. REVIEW OF THE THEORY OF CREEP.

The textile fibres, natural or man-made, are high polymers and their structures consist essentially of long, flexible chains formed by groups of atoms, the pattern repeating itself at regular intervals. Each such group represents the molecule of a well-defined chemical substance. The long flexible chains exist partly in well aligned compact bundles and partly in a chaotic distribution of the chain elements. The compact parallel chains, held together by the secondary valence bonds, exhibit repetition of atomic space-lattice like ordinary crystals, under X-rays. The chaotically distributed regions of the chains on the other hand, exhibit a powder X-ray diagram such as is associated with amorphous substances.

According to the Kinetic theory, the constituent molecules of a solid, execute restricted vibratory motions about a central position determined by the Van der Waals forces. These vibrations are likely to occur over wider amplitudes in the less densely packed amorphous regions (Hermans, 1946). This fact makes the vibrating elongated molecules in this region more liable than in the crystalline regions, to be torn away, displaced or rotated (by smaller stress or to greater extent), thereby disturbing the field-energy equilibrium of the molecular distribution. Therefore, in the amorphous region of the fibre, it may even be possible to easily bring about a re-distribution of the molecules, and so alter the total potential energy of the field of the electrical residual-valence-forces by means of an externally applied stress. Even newly aligned bundles or crystallites may be formed from the previously chaotically distributed molecular chains under such stress.

In the case of the jute filaments, in addition to the structural amorphism of the long-chain cellulose molecules (which constitute the elementary cells that make up the major part of the filament body) there exist also *other* amorphous embedding, binding and lubricating substances¹ like lignin, hemicellulose, fats and waxes. The elementary cells occur in the form of bundles, arranged, by relative longitudinal shift, into a continuous system along the whole filament length just as the fibres happen to be disposed in a yarn of which the twist has been removed.

¹ On an average, a jute filament contains about 60% α -cellulose (which make up the elementary cells), 29% hemicellulose (binding material), 10% lignin (embedding and binding substance) and 1% fats and waxes (lubricators).

In respect of fine structure, therefore, the jute filament differs largely from nylon, rayon, etc., in which case only *one* kind of chemically homogeneous substance is concerned. It also differs from the natural fibre, cotton, in as much as the filament of the latter consists of but a single, long elementary cell of cellulose.

Now, creep may be physically described as the change in the condition of strain in a material, produced *with time*, for example, (i) when the applied stress is kept constant, an increasing strain being developed with the process of time and tending to a limit, and the original condition being approached, or wholly recovered, in time, when the stress is withdrawn after application for a specified period, or (ii) when the material is allowed to relax with time under a constant stretch. For jute, naturally, the great structural non-homogeneity within a filament is likely to initiate considerable difference in the nature of the strain which different parts may experience with time under a particular external stress.

In the discussion of the theory, the applied stress will be considered to be of the nature of a longitudinal tension along the filament axis. This will actually correspond with the condition of the present experiments.

The general nature of creep has been described clearly by Leaderman (1943) who has also indicated, after Weber, how by repeated loading and unloading, a material may be mechanically conditioned, so that the 'secondary creep' which is not easily recoverable, is eliminated, and the behaviour of the easily recoverable 'primary creep' made amenable to direct study. For the mechanical conditioning of a test specimen to be effective, the observations should be confined to a smaller load than that used for conditioning. It may be pointed out here that lately it has been recorded by Burte, Halsey and Dillon (1948) that the 'secondary creep is rather rare in textile fibres'. They however worked on wool fibres which differ fundamentally in structure (as well as constituents) from the jute filaments.

When of course the applied stress is sufficiently large, another type of permanent set is produced in the filament. This, like the Hookean change, is also a general property of matter. This permanent set involves actual flow of the material, and is totally irrecoverable by physical means. This kind of rheological change is known as 'plastic' deformation.

The behaviour of a *quasi*-crystalline high polymer like a textile filament, can, under external stress, be separated into three components. The actual behaviour observed is the effect of superposition of the separate events that take place independently of one another. However, one or more of the individual causes associated with the three components may of course predominate under different conditions of stress. The three components in simple form, are indicated respectively in Fig. 1, as being—

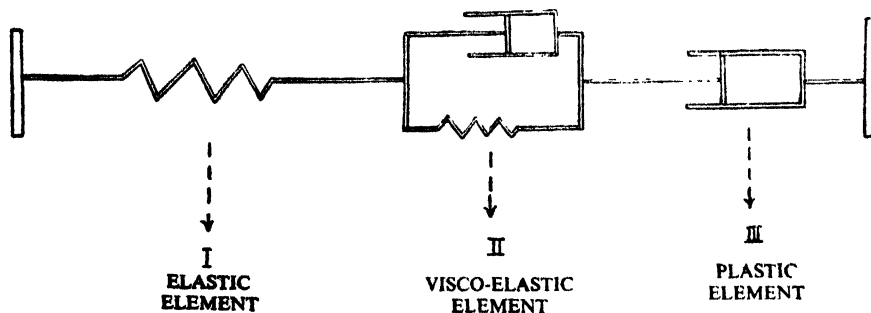


Fig. 1. MECHANICAL MODEL OF A TEXTILE FILAMENT

- (i) a perfectly elastic or Hookean change such as is observed in the case of a spring (Part I);
- (ii) a viscous change similar to the motion of the piston in a Newtonian dash-pot (Part III); and
- (iii) a complex visco-elastic change formed by the combination of a Hookean spring and a Newtonian dash-pot (Part II).

The complete figure (Fig. 1) may be said to represent functionally in respect of the elastic properties, a model textile filament. In spite of the likelihood that all the three components may co-exist from the very start of the application of stress, there is, however, clear indication that each one visibly supervenes the other in the order marked in Fig. 1. Thus the plastic deformation can manifest itself prominently only when the deformations of the other two kinds have been completed *ad seriatim*, under suitably large stress.

When the applied stress is very small, the plastic deformation may, therefore, be ruled out, and the total extension becomes the sum total of the instantaneous Hookean extension and the delayed elastic extension or creep. The creep has been shown by different workers (Leaderman, 1943; Weber, 1835, 1841; Kohlrausch, 1866) to be dependent simultaneously on the Hookean extension on the one hand and a function of the time of application of load on the other. Jordan (1915) basing his arguments on Boltzman's 'recollection theory' (Boltzman, 1876) derived a simple logarithmic law for the time function. Thus, if E_H represents the Hookean extension, the total creep = $E_H f(t)$, t being the duration of stress. After Jordan, we may in the simplest way put creep = $E_H \log t$. The recovery from creep, when the applied stress is withdrawn, has been known to be more or less reversed in both magnitude and direction.

The creep and the recovery of a textile filament is known to depend on the magnitude of the applied load on the one hand, and on the other, on the nature, length and structure of the material, i.e. on length, density, gravimetric fineness and Young's modulus. Now, in the case of a jute filament, there are many discontinuities in the structure due to the pores, the lumens of the constituent elementary cells, and much lack of homogeneity due to the nature of the component substances. So, the density is liable to vary from point to point. Naturally, the phenomenon of creep as well as that of recovery from it, must be *quantitatively* a very complex measure.

As Hermans (*loc. cit.*) has pointed out, there may be, even in a purely cellulose fibre, an infinite number of ways of the molecular distribution among the crystalline and, particularly, among the randomly occurring amorphous parts. Due to this feature also, the complexity increases many fold, especially in the matter of distribution of the amorphous materials, when there are more than one non-cellulosic substances present as in a jute filament. Any *quantitative* estimation of character, depending on such plurality of materials in an infinity of anisotropic distribution, is impossible in the present state of knowledge. Future approach to the problem needs must be statistical rather than physical.

So, the utmost that can be said is that the quantitative response to the applied external force is only some average statistical effect with wide range of possibilities of variation. So, even for different filaments of the same variety, much less to speak of different varieties themselves, the order of value of the observed effect may differ considerably largely. However, the qualitative character of response to external force so far as the materials and the general structural features remain unaltered, should not exhibit considerable difference, at least between filament and filament. On this basis, the time-relative observations on only a few filaments, however differently responsive quantitatively by themselves, will, on averaging, indicate the required time-effect fairly significantly, and quite faithfully. It may be stated here that Meredith (1945) carried out his tensile elasticity measurements on *five filaments*

only, the filaments being nearest the mean fineness of the material. He pointed out that 'the activation energies of the molecular bonds which are responsible for the time-effects in most textile fibres are all of the same order of magnitude'.

3. APPARATUS, EXPERIMENTAL TECHNIQUE AND MATERIAL.

(a) Apparatus:

A sketch of the apparatus used for the present experiments, is given in Fig. 2. A part of the assembly, used in some of the experiments, is also shown separately in Fig. 2A. The functions of the different features in the assembly, are discussed below.

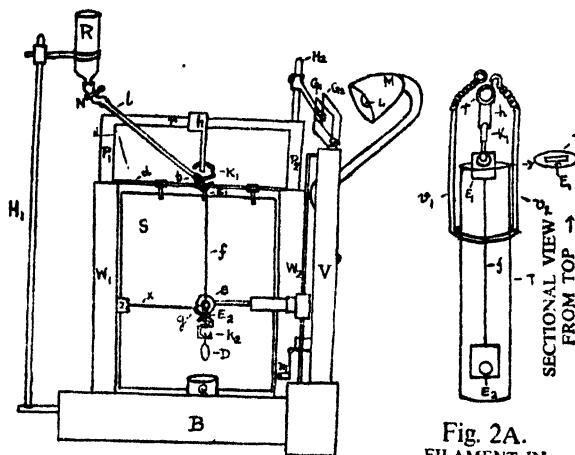


Fig. 2. CREEP TESTER ASSEMBLY

Fig. 2A.
FILAMENT IN
WETTING
CYLINDER

- B—Wooden Base of Assembly;
- D—Load applied, in conjunction with hook, k_2 ;
- E_1, E_2 —Upper and lower eyelets carrying filament;
- G_1, G_2 —Air separated glass plates;
- H_1, H_2 —Stands with clamp;
- k_1, k_2 —Hooks for catching eyelets E_1 and E_2 ;
- L—Lamp; M—Reflecting parabolic Mirror;
- N—Pinch-cock to regulate flow;
- P_1, P_2 —Vertical steel pillars on walls W_1, W_2 ;
- Q—Beaker for collecting water used to keep the fibre moist during wet tests;
- R—Water Reservoir; T—Elliptical plastic cylinder for wetting fibre *in situ* (Fig. 2A).
- S—Black screen hanging from d to offer a contrasty background for filament under test;
- V—Vernier microscope;
- W_1, W_2 —Upright wooden walls on B;
- X—A metal wire bent at right angles, used to keep freely hanging eyelet E_2 steady;
- Z—Velvet cork attached to W_1 at right angles, to hold X with the bent arm of the latter towards observer;
- d—horizontal bar connecting W_1, W_2 and holding S;
- e—field of view of V focussed on to the top of E_2 ;
- f—filament under test;
- g—glass capillary tube sliding over the free bent arm of X and just touching the eyelet E_2 ;
- h—a vertical strip from the middle of r pointing towards bottom;
- l—capillary outlet tube for keeping fibre *in situ* wet during test;
- m—reading lens for V-scale;
- n—horizontal rod connecting P_1, P_2 and holding h;
- t—cotton thread lead for water drops from l to E_1 ; and
- v_1, v_2 —wire supports for T when in use; these are hooked at the free end to hold on to r,

The wire-support (X) used for preventing the lateral vibration or twisting of the fibre-pendulum, should be such that the hanging eyelet (E_2) can easily slide up or down as contraction or elongation of the filament occurs. To effect this, in the present case, the free bent arm of the wire (X) was capped with a round capillary glass tube (g).

The weight of the eyelet (E_2) should be such that while it produces no significant strain in the filament (f), it is sufficient to keep the filament straight and free from curvatures or kinks. In the present case, the mass of the aluminium eyelets was nearly 0.38 gm.

At the time of making an observation, light from the lamp (L), both direct and reflected from mirror (M), was allowed to fall on the eyelet (E_2). The light before falling on this was made to pass through the plate glasses (G_1, G_2) placed near the lamp and the mirror. The glass plates were separated by an air-gap. The arrangement prevented any undue heating up of the filament or the atmosphere around it by radiation from the lamp during the few seconds required for adjusting the cross-wire of the vernier microscope (V) for a reading.

For observation in the soaking wet condition, the filament was wetted *in situ* in an elliptical plastic cylinder (T'). After the specified period of wetting, the cylinder was removed, and water from the reservoir (R) was allowed to trickle down from the cotton-thread lead (t) which was placed in contact with the fixed eyelet (E_1). The water running down along the filament, on to the eyelet (E_2) was collected as it dropped out in the beaker (Q) and was thrown away. The cotton thread lead was found useful for both keeping up a continuous steady flow and preventing any undue vibration of the suspended filament during the water-dripping treatment to keep it moist.

The cylinder (T'), due to its elliptical cross-section, checked the turning round of the eyelet (E_2) during the wetting of the filament and thereby twisting it. In inserting or removing the cylinder (T'), utmost care was exercised so as not to give any shock to, or allow any twisting of, the filament (f).

(b) *Experimental Technique :*

For carrying out the actual experiments, at first single filaments of a variety, greater than 13 cms. in length, were prepared by hand from a test sample, according to the technique indicated before (Sen & Nodder, 1944). The filaments were then cut down as accurately as possible, to 13 cms. In order to obtain the test filaments for a sample, fifty 13 cm. filaments, picked up at random, were weighed individually on a sensitive phosphor-bronze torsion micro-balance reading up to 0.01 mg. After weighing, each filament was kept separate in a cover with the observed mass noted on it. When all the fifty filaments had thus been weighed and preserved, five filaments out of those possessing one particular mass, were grouped together. Then another such group of five filaments possessing a substantially different mass from that of the first group, was similarly collected. In this way, two different mass-groups of five filaments each, were obtained for test in the case of each jute variety. The present measurements for data of a particular category, were confined to the five filaments of the same fineness (i.e. mass-group).

For examination, each filament was mounted firmly with a suitably hard mixture of shellac and paraffin, on two aluminium eyelets at exactly 10 cms. apart. The length of 10 cms. therefore represented the unstrained initial length of a filament under test. Smaller test length may assure better uniformity of diameter, but the extension under a small load would be too little to permit reasonably accurate measurement. The mounted filament was at this stage mechanically conditioned in the case of observations carried out in the air-dry state.

Mechanical conditioning, wherever needed, was carried out by loading and unloading alternately for two-hour periods, the complete operations being carried

out twice successively, as indicated by Leaderman (*loc. cit.*). The load used on a filament for mechanical conditioning was 4.62 gms., while the testing load was 1.80 gm. The length of the filament actually put under the testing load was most probably slightly greater than 10 cms. on account of any secondary creep having been stabilised by mechanical conditioning. Unfortunately, the length-reading just before the starting of the mechanical conditioning was not recorded. So, any record of excess over 10 cms. at the start of loading for test, is not now available. This, however, does not affect the results, or their qualitative consideration which only has been done here. It may also be remembered that Burte *et al.* (*loc. cit.*) pronounced the secondary creep to be rather rare in the case of textile fibres.

For an observation on a filament, the vernier microscope was focussed on to one particular mark on the eyelet (E_2 in Fig. 2) and the cross-wire put in alignment with it. At first the zero-reading was obtained. Then the load of 1.80 gm. was carefully added with the help of a pair of forceps. This load was hung by attaching the carrier hook fixed on the load, and together weighing 1.8 gm., on to the eyelet. Immediately, the reading for instantaneous extension was recorded. The effect on the creep during brief interval of probably a second or two which elapsed between the attachment of the load on to the eyelet and the adjustment of the microscope cross-wire into alignment with the mark on the eyelet (E_2), was from the circumstances, liable to be ignored. Subsequently, the extension was read every half-hour from start, until two hours of loading had been just completed. Just a second or two prior to the expiry of the 2-hour interval, the last extension-reading was taken, and immediately afterwards the load was carefully removed. The instantaneous contraction in length which followed, was immediately, i.e. within a second or two, read as before. Later, contraction was successively noted over two hours following unloading, at every half-hour intervals.

The procedure for the wet filaments, so far as loading, unloading and measurements of length changes were concerned, was the same as for the air-dry filaments. There was, however, no mechanical conditioning in these cases. The filament, before observation started, was wetted in the elliptical cylinder for one full hour.

In the case of investigation of rapidity of removal by wetting of any creep deformation previously effected in the air-dry condition, the filament was not mechanically conditioned. After observation of the instantaneous extension on application of the 1.80 gm. load, the filament was allowed to remain under load for 18 hours. Then, after noting the total extension reading, the load was carefully taken away, and the instantaneous contraction noted as before. The next observation of contraction in the air-dry state, was carried out one hour later. Then the filament was wetted in water inside the elliptical cylinder for 15 minutes only. Finally, the elliptical cylinder was removed, and the length-reading again obtained.

(c) Materials :

Six varieties of jute ranging widely in spinning quality (as determined at present), were examined for the creep and the recovery tests in the air-dry condition. Four of these varieties were tested in the wet condition. These latter varieties were also examined for the rapidity of dissolution of imposed strain on wetting. The particulars of all the six varieties are given in Table I, the four of them tested wet, etc., have been marked with asterisk.

4. PRESENTATION OF THE RESULTS.

The detailed mean values of the observations made on the five separate filaments of a variety, are given in the Appendices, A, B & C. The study of the varietal mean values of the different sets, was based on the data suitably arranged hereunder.

TABLE I.
Particulars of Jute varieties examined.

Jute Ref. No.	Variety.	Quality number ¹	Description.	Grade	Source.
J 574T ..	Tossa ..	126	Commercial (1941-42)—Mymensingh.	Top	B.J.D.A.
J 572T* ..	Tossa ..	114	Commercial (1941-42)—Kishanganj.	Middle	B.J.D.A.
J 1712T*	Tossa ..	87	Experimental Trial (1946-47) Line vs. Broadcast sowing.		Chinsurah Farm.
J 578W* ..	White ..	96	Commercial (1941-42)—Serajganj.	Middle	B.J.D.A.
J 963W ..	White ..	90	Commercial (1943)—?	Middle	?
J 1757W*	White ..	63	Varietal test (1946-47)		J.A.R.L (ICJC) Dacca.

¹ From standard 10 lb. hess. weft yarn (*vide* Tech. Res. Memoir, I.C.J.C. No. 1). Quality number indicates percentage. Single Thread Strength (lbs.) to grist (lbs./spy).

(a) *General behaviour of Creep and its recovery :*

One normally expects that, in the case of the Hookean or instantaneous strain in ordinary condition, the extension under load should be equal to the contraction which takes place when the load is removed. This being a general property of matter, it should also hold in the case of a jute filament, when the applied load is not large enough to cause immediate plastic flow. The actual observations made in the air-dry state, recorded in Table II, however, reveal a deficit in respect of contraction in all cases but one. The amount of lag observed in the matter of recovery is, no doubt, generally small; but in a few cases a relatively larger deficit is found to occur. The extent of lag is apparently different for different varieties as well as for different degrees of fineness of filaments of the same variety.

TABLE II.
Instantaneous Extension and Contraction in the air-dry state.

Jute Ref. No.	Gravimetric fineness, μ (microgm./cm.).	Instantaneous.		Difference (a) - (b).
		(a) Extension under load ($\times 10^{-3}$ cm.).	(b) Contraction on removing load ($\times 10^{-3}$ cm.).	
J 572T	15.4	48.0	48.0	0.0
	19.2	35.6	31.2	4.4
J 574T	11.5	29.2	27.6	1.6
	19.2	14.4	11.2	3.2
J 1712T	23.1	12.8	10.4	2.4
	30.1	9.6	7.2	2.4
J 578W	11.5	28.0	25.2	2.8
	19.2	9.6	7.6	2.0
J 963W	19.2	12.4	10.8	1.6
	23.1	9.6	5.6	4.0
J 1757W	30.1	10.0	8.8	1.2
	38.5	7.6	6.4	1.2

Similar record of observations on wet filament, is given in Table III. In some cases at least, for identical filament fineness, the wet condition seems to cause a larger deficit in instantaneous contraction than does the air-dry condition.

TABLE III.
Instantaneous Extension and Contraction of wet filaments.

Jute Ref. No.	Gravimetric fineness, μ (microgin./cm.).	Instantaneous.		Difference (a) - (b)
		(a) Extension under load ($\times 10^{-3}$ cm.).	(b) Contraction on removing load ($\times 10^{-3}$ cm.).	
J 572T	11.5	15.6	11.6	4.0
	15.4	10.4	8.8	1.6
J 1712T	23.1	10.8	8.4	2.4
	30.1	13.2	8.4	4.8
J 578W	11.5	10.8	8.8	2.0
	15.4	11.2	8.8	2.4
J 1757W	19.2	12.0	8.4	3.6
	30.1	12.4	7.6	4.8

It is seen that there is likelihood of greater uniformity among varieties in respect of both the extension and the contraction values in the wet state than in the dry state.

The data for the creep and the creep-recovery in equal periods, in both the dry and the wet states, are given in Table IV.

The case in the air-dry condition, in which a large difference (+4.8) occurred, was one where the experiments were carried out in humid atmosphere (R.H. 84%), and the temperature at the time was also fairly high (85°F.). For others tested in the air-dry state, the relative humidity did not exceed 77%. These cases exhibit practically complete recovery within the same period as creep. The small differences which are visible, occur with both the positive and the negative signs, and may have been due to experimental error.

In the case of the wet filaments, however, except one case in which recovery equals creep, the lag is all in one direction only, and is generally of considerable magnitude.

(b) *Effect of Wetting on Pre-imposed Creep:*

It was pointed out earlier how a series of experiments was conducted in order to study the rapidity of dissolution of strain imposed in air-dry state, by wetting the filament. The results obtained, are stated in Table V.

From this table it is found that a very considerable amount of recovery occurs very rapidly on wetting even for 15 minutes only. The relative effect of wetting can be judged from the ratio, c/b . The shrinkage on wetting is obviously so great that invariably there is reduction in length *below* the original (test) length of 10 cms. It is not known whether the whole of this contraction is caused by the relief obtained from all pre-existing strains, e.g. from secondary creep, previous history of the filament, etc. or due to the effect of any significant lateral swelling in water.

The data for filaments of the same fineness in respect of the initial creep in the first 2 hours and the total creep in 18 hours, are stated in Table VI. The data refer to the air-dry condition.

TABLE IV.

Creep and recovery in 2-hour periods in air-dry and wet states.

Ref. No.	μ (Air-dry) in 75% R.H. (microgm. per cm.)	Air dry state.					Wet state.			
		(X) Creep ($\times 10^{-3}$ cm.)	(Y) Recovery ($\times 10^{-3}$ cm.)	Difference (X - Y)	R.H. (%)	Temp. °F.	(x) Creep ($\times 10^{-3}$ cm.)	(y) Recovery ($\times 10^{-3}$ cm.)	Difference (x - y)	Temp. °F.
J 572T ..	11.5	..	..	..	..	..	12.4	10.0	+2.4	89
	15.4	9.6	4.8	+4.8	84	85	14.8	8.0	+6.8	89
	19.2	6.0	4.0	+2.0	77	87	..	..	..	..
J 574T ..	11.5	2.8	1.6	+1.2	73	78	..	..	..	..
	19.2	2.8	4.0	-1.2	75	78	..	..	..	..
J 1712T ..	23.1	3.6	3.6	0.0	64	82	12.4	8.4	+4.0	86
	30.1	2.8	3.6	-0.8	70	84	6.4	6.4	0.0	86
J 578W ..	11.5	4.0	4.4	-0.4	66	84	14.0	8.8	+5.2	91
	15.4	..	..	..	..	..	13.2	8.8	+4.4	86
	19.2	3.6	2.8	+0.8	59	80	..	..	..	..
J 963W ..	19.2	2.8	2.8	0.0	74	79	..	..	..	..
	23.1	2.0	3.2	-1.2	69	81	..	..	..	..
J 1757W ..	19.2	..	..	..	..	..	9.6	7.2	+2.4	86
	30.1	3.6	2.4	+1.2	71	87	6.4	5.6	+0.8	86
	38.5	3.2	2.0	+1.2	75	86	..	..	..	..

TABLE V.

The effect of wetting on pre-imposed creep.

Jute Ref. No.	μ (Air-dry) in 75% R.H. (microgm. per cm.)	Air-dry state.			(c) Further recovery on wetting for 15 mins. in water after (b) ($\times 10^{-3}$ cm.)	Ratio c/b.
		(a) Total creep in 18 hrs. ($\times 10^{-3}$ cm.)	(b) Recovery in 1 hr. after deloading ($\times 10^{-3}$ cm.)	(a-b) Residual creep before wetting ($\times 10^{-3}$ cm.)		
J 572T ..	11.5	7.6	2.0	5.6	14.0	7.00
	15.4	13.6	4.8	8.8	20.4	4.25
J 578W ..	11.5	10.0	5.6	4.4	19.2	3.43
	15.4	8.4	3.6	4.8	10.0	2.78
J 1712T ..	23.1	4.8	5.2	-0.4 (?)	5.6	1.08
	30.8	3.6	2.8	0.8	8.0	2.86
J 1757W ..	19.2	8.0	1.6	6.4	10.9	6.81
	30.8	7.2	3.6	3.6	8.0	2.22

TABLE VI.

Primary Creep in 2 hours vs. Total Creep in 18 hours.

• Ref. No.	μ (air-dry) in 75% R.H. (microgm./cm.)	(A) Primary creep in 2 hours ($\times 10^{-8}$ cm.)	(B) Total creep in 18 hours ($\times 10^{-8}$ cm.)	Difference (B - A).
J 572T ..	15.4	9.6	13.6	4.0
J 578W ..	11.5	4.0	10.0	6.0
J 1712T ..	23.1	3.6	4.8	1.2
	30/31	2.8*	3.6†	0.8
J 1757W ..	30/31	3.6*	7.2†	3.6

* $\mu = 30.1 \times 10^{-6}$ gm./cm.† $\mu = 30.8 \times 10^{-6}$ gm./cm.

If the secondary creep is considered to be non-existent in the case of jute filament after Burte, Halsey and Dillon (*loc. cit.*), the overall mean primary creep-rate and the mean rates at the beginning and after the first 2 hours, are easily obtained from the observed data. These rates are given in Table VII for those cases where the filaments are of identical gravimetric fineness. If, however, the secondary creep is present, these figures will indicate the total creep rates.

TABLE VII.

Various creep rates for filaments of the same fineness.

Specification of Time considered.	Creep rate (cm./min).		
	J 572T ($\mu = 15.4 \times 10^{-6}$ gm./cm.)	J 578W ($\mu = 11.5 \times 10^{-6}$ gm./cm.)	J 1712T ($\mu = 23.1 \times 10^{-6}$ gm./cm.)
1. Over-all ..	0.0000126	0.0000092	0.0000044
2. Beginning or first 2 hours ..	0.0000800	0.0000333	0.0000300
3. After first 2 hours ..	0.0000042	0.0000063	0.0000013

5. DISCUSSION OF THE RESULTS.

(a) *Instantaneous change on loading and unloading:*

Some varietal differences in the elastic response of filaments, as well as a lag in the matter of recovery of elastic or instantaneous extension have been noted in Tables II and III. The complex constitution of the amorphous region of the jute filament naturally indicates the likelihood of differential response of parts to any externally applied stress. This may result in varietal differences in the elastic behaviour. To obtain an idea of the causes which operate in producing the lag, it is necessary to direct attention to the fine structure of the filament more closely.

It is known that the axes of the elongated molecules of the chain-polymers in the amorphous region, which make up a jute cell, point in all possible directions, as also do the crystalline aggregates of molecules. The action of the applied longitudinal stress tends to more or less, bring the axes of these molecules of the amorphous region into alignment. This is supported by the fact that when a directed stress is applied to a filament, the X-ray diffraction photograph shows much stronger crystallinity than in the unstretched condition. As different molecules

get oriented to different extent, varying from zero to a maximum depending upon the magnitude of the applied stress as well as the internal resisting forces, the observed effect must be a statistical average 'over a large number of molecular events' (Fürth, 1948). But actual 'flow occurs if the local strain becomes too great' (Meredith and Peirce, 1948) for the primary valence bonds, the Van der Waals bonds, etc., to resist.

Now, it is a statistical fact that the greater the variability of a system, the greater is the likelihood of an extreme value occurring. The jute filament being an extremely complex and compound structure, the distribution of the internal strain developed in different parts under a definite external stress, is liable to be very highly heteroform. It is natural to expect, therefore, that the induced local strains should, in some parts or other, be too great to maintain the existing molecular disposition or cohesion and a new equilibrium distribution should occur. This creates the probability of some flow-displacement, however small, such as may not be easily recoverable after removal of stress. There are also other ways in which a restricted flow may occur. The orientation of molecules may bring about an alignment of new molecular chains, more or less perfectly, creating fresh crystalline structures which resist break up even on withdrawal of stress. Fissuring of the crystallites at the ends may also lead to a kind of flow, as Leaderman indicates (*loc. cit.*, p. 101). While new crystal formation is favoured in textile fibres by stretching in the wet state, the fissure effect is brought to pass by stretching dry. Now, in the former case the forces required to be overcome are only the secondary valence or field forces, while for the latter, where fissuring of crystallites is concerned, the primary valence forces which are of course very much stronger than the secondary, are required to be supervened *in addition*. Thus the alignment of chains into crystalline or *semi*-crystalline states is a more probable event and is likely to be the cause of the observed lag. The greater prominence of the lag in the wet state falls in line with the view indicated.

In a wet filament where water molecules have penetrated the body no doubt mainly, if not wholly, in the amorphous region, a greater overall facility of molecular orientation is likely because of the weakening of the secondary valence bonds between the molecular chains owing to the interpenetrating water molecules. An optimum number of molecules are likely to be oriented under external tension, or rehabilitated as far as possible into the previous positions when the tension is removed. The greater facility of orientation in the wet state of the filament is thus likely to be responsible for the observed great uniformity of instantaneous extension or contraction of the wet filament. In high humidity, the moisture penetrates inter-molecular regions in the state of vapour. Consequent absence of swelling does not lead to large reduction of the secondary bonds; but of course the vaporous moisture molecules serve as lubricators in the matter of orientation of the molecular chains. Such circumstance is likely to result in complete recovery of instantaneous extensions, as found in one case.

(b) *The Creep and the Recovery of strain :*

The observed effects as given in Table IV, may be considered from a thermodynamical standpoint. The discussion is given below.

The strained internal state of the filament may be regarded as a function of the two independent variables, viz., the applied tension, P and the absolute temperature, θ . The length of the filament under test being l , when θ and P suffer very small changes, the element of heat, dq , received by the filament is given by

$$dq = \psi d\theta + a dP \quad \dots \quad (I)$$

Here, ψ represents the thermal capacity of the whole filament, and is a positive quantity; and a is a thermal coefficient which is a function of θ and P . Now,

when the length l , is increased to $l+dl$ under tension, P , the work done on the filament is $-P.dl$. Let U be the intrinsic energy of the filament and ϕ its entropy. Then by the *First Law of Thermodynamics*,

$$dq = dU + (-P.dl) \quad \dots \quad (II)$$

Eliminating dq from the equations (I) and (II), we get,

$$dU = \left(\psi + P \frac{dl}{d\theta} \right) d\theta + \left(a + P \frac{dl}{dP} \right) dP \quad \dots \quad (III)$$

Again, by the *Second Law of Thermodynamics*,

$$d\phi = \frac{dq}{\theta} = \frac{\psi}{\theta} d\theta + \frac{a}{\theta} dP \quad \dots \quad (IV)$$

Since both dU and $d\phi$ are perfect differentials, we have from the equations (III) and (IV), by elimination of the quantity

$$\left(\frac{\partial \psi}{\partial P} - \frac{\partial a}{\partial \theta} \right) = 0$$

$$\frac{\partial l}{\partial \theta} = \frac{a}{\theta} \quad \dots \quad (V)$$

As the length of a textile filament like jute, increases with heat, $\frac{\partial l}{\partial \theta}$ is positive. So a is also positive.

Now, when a jute filament is suddenly stretched by the application of an external tension, P (the tension in fact suddenly increases from zero to P), there is little possibility of similarly sudden equalisation of all internal temperatures of the heterogeneous material constituting the jute filament, with the outside temperatures. So, the change may be regarded as *adiabatic*. That makes $dq = 0$, and so,

$$\psi d\theta + a dP = 0 \quad \dots \quad (VI)$$

Since ψ , a and dP are all positive, $d\theta$ must be negative. In other words, the instantaneous extension under load is an *endothermic* process. During instantaneous contraction, dP is negative, and because ψ and a are positive, $d\theta$ must be positive. The contraction process is therefore an *exothermic* one.

Hence, while in the case of sudden extension, the ensuing fall in temperature makes the molecular system of the jute filament liable to absorb heat from outside, the opposite effect occurs in the case of sudden contraction.

Further, in a region inside the filament bounded by surface, since the specific heat of all natural cellulosic filaments is more or less steady, the internal flow of heat will be governed by the density of distribution of the constituent substances of the filament from point to point, in addition to the coefficient of conductivity. In the light of these considerations (cf. Houstoun, 1920) we may proceed to study the creep and the recovery of the jute filament thus.

When a jute filament is suddenly longitudinally stretched by the application of an external load, due to the fall in temperature which necessarily occurs internally, the natural thermal agitation of the molecules, as a whole or in part, is restricted. Considerable resistance is thereupon liable to develop to any attempt to orientate the molecules in the direction of the filament axis. At the end of the instantaneous change, heat begins to flow gradually into the filament from outside. The agitation of the molecules thus again gradually increases. The impediment to equalisation of temperature is offered by the density differences. As a result of the slow recovery of the thermal condition there is a slow recovery of the original condition of molecular agitation. Thus, following instantaneous elongation, further gradual elongation,

at a considerably slow rate, results, as the molecules, with the absorption of heat from outside, become more and more agitated, and thereupon more easily amenable to the action of the applied stress. (Apparent reduction of inertia under dynamic conditions is also a common macroscopic experience.)

Now, since the elongated molecules, both of the amorphous and the crystalline categories, have infinite possibilities of orientation (*vide ante*), the orientations must generally be *random*. The number of molecules which can at one time be turned to the maximum extent towards the direction of tension will depend on the extent of orientation, in addition to the magnitude of the applied tension as well as of the internal resisting forces. When the applied tension is constant, and as the internal resisting forces are themselves a function of the disposition of the oriented molecules, the degree of orientation seems most likely to be the limiting factor in determining the number of molecules involved at a time. So, on account of random distribution of orientation this number will obey the Gaussian or normal statistical law of distribution, as time progresses. This therefore is probably the basis of the exponential law found by Jordan (*loc. cit.*).

The gradual fall in the rate of the delayed elongation as a result of molecules with larger and larger deviation from the direction of tension being encountered in Gaussian proportions, has been stressed by the earlier workers also. A stage in this process is thus ultimately reached when the applied stress proves inadequate to force further molecular orientation. When this condition is reached, the time-relative elongation stops. The possibility of a progressive fall in the rate is indicated by the data given in Table VII.

As the applied load is removed, following the instantaneous contraction which takes place, there is an increase of internal temperature. This leads to increase of molecular agitation. An easy restoration of the oriented and/or aligned molecules towards the original state, under the restoring influence of the secondary valence forces, therefore, takes place. However, as excess heat flows out, the temperature gradually comes down to the original condition. As a result, the recovery also slowly decreases, and ultimately stops. Thus the process of recovery becomes almost an inversion of that of creep.

Due to the density variations within the filament, heat transference is faster in some regions than in others. This fact brings about a change in the relative disposition of the molecules resulting in a new equilibrium condition. This effect probably manifests itself as the difficultly recoverable set, called the 'secondary creep'. This has also been considered in the previous section. Naturally, therefore, secondary creep once developed, remains unaltered as long as the stress again applied happens to be equal or less. Thus, with a mechanically conditioned filament tested under a smaller load than that of conditioning, recovery is likely to be practically complete in the air-dry condition wherein molecular orientation is more common than molecular alignment into crystalline structure. This is probably the explanation of the data for more or less complete recovery for air-dry filaments given in Table IV.

In the case of the wet filaments, it can be easily shown (from a consideration of the possible evolution of heat by swelling of the jute fibre in water) by reference to Herman's data for cellulose (*loc. cit.*, p. 33), as well as of the specific heat of jute quoted in Matthew's Textile Fibres, 5th Ed., p. 46 (Mauersberger, 1947), that the temperature developed in course of the present wetting treatment was insignificant at the time when the filament was put under test. However, due to the considerable swelling (Macmillan, 1939) which occurs, through the presence of the water molecules in the liquid phase within the filament body, especially the amorphous parts, in the wet condition, the secondary valence bonds between the amorphous chain-molecules are weakened. Molecular orientation thus becomes easier than under the air-dry condition. Naturally, a large value of creep of wet filaments may be expected. Also, due to more likely formation of crystalline alignment there is probably greater

resistance to recovery. This is due to show up as a large lag. These expectations are realised in the data for wet jute filaments given in Table IV.

(c) *Effect of Wetting on creep developed in the Air-dry State :*

It was found that very rapid recovery from creep occurred on wetting a previously strained jute filament for 15 minutes only. Lateral swelling which may go up to 21 % (Macmillan, *loc. cit.*), acting in conjunction with the weakening of the secondary bonds between chains, caused by the inter-penetrating water molecules, may be responsible for the quick dissolution of strain.

During this experiment it was observed also that the contraction on wetting led to reduction of the filament length *below the original (test) length*. This was found to occur in *all* cases. No definite statement on this is yet possible, but it may have been caused by the liquidation of some pre-existing strain developed during the production of the fibre or in the course of filamentation by hand. The extra contraction in length cannot of course be ascribed to swelling as Macmillan (*loc. cit.*) found longitudinal change on swelling to be insignificantly small in a jute fibre.

(d) *Diagrammatic Study of the Qualities Investigated :*

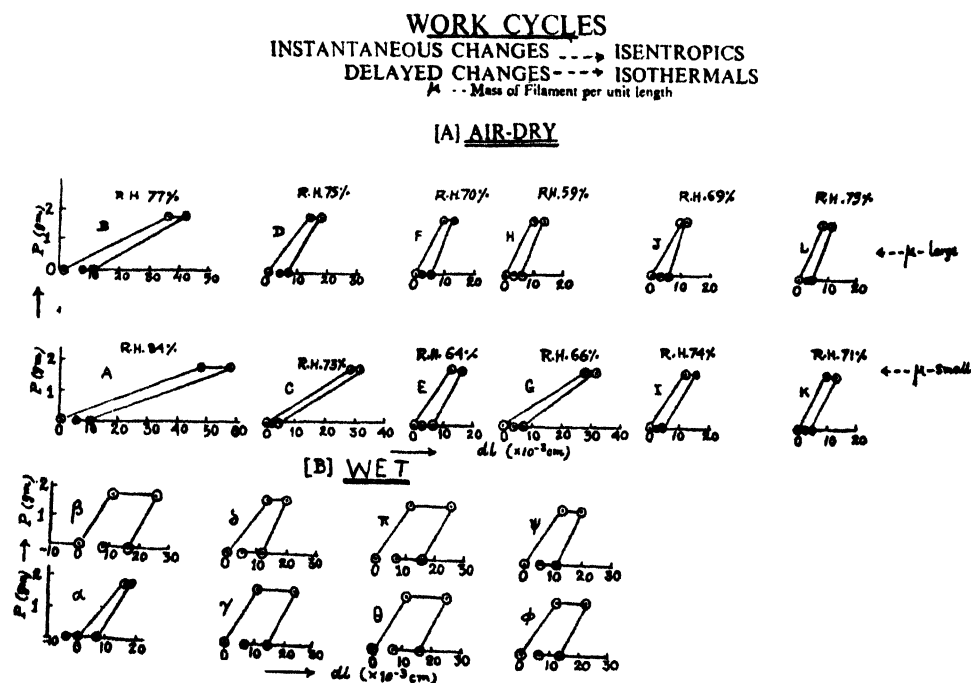
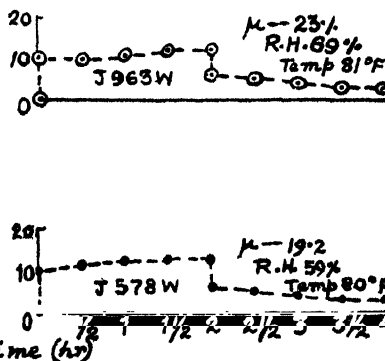
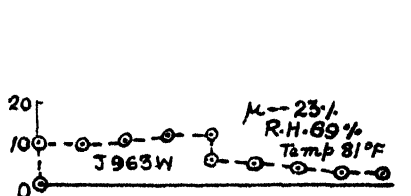
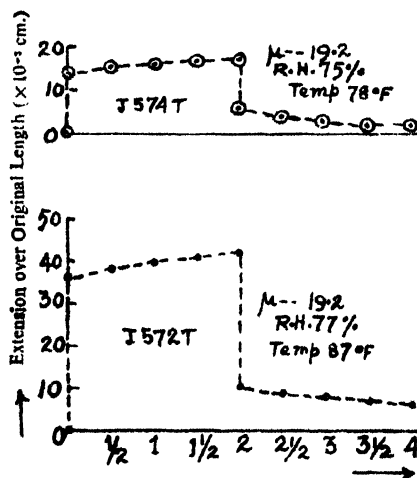
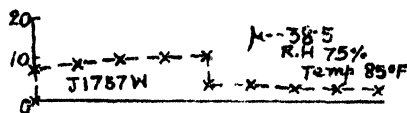
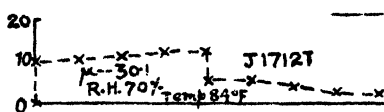
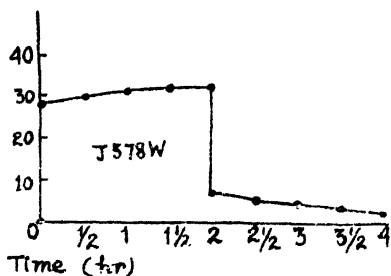
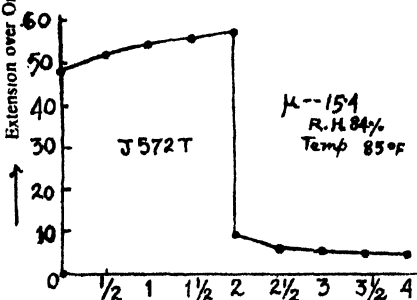
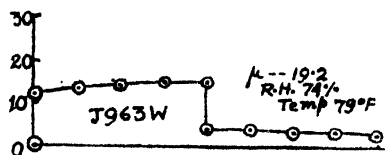
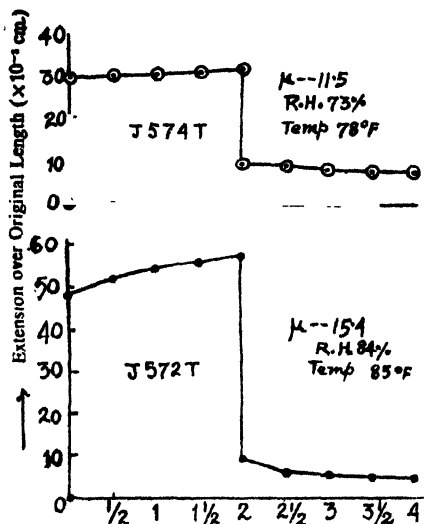
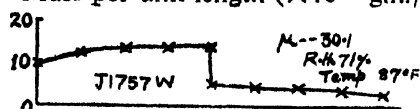
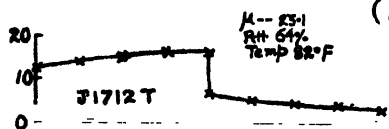


Fig. 3.

Fig. 3 represents the Carnot (work)-cycle obtained by taking a filament through a loading-creep-unloading-recovery track. In all air-dry cases and all but one wet cases, an open cycle is obtained indicating irreversible dissipation of energy. In the one case where an exception is observed, recovery in two hours seems to have proceeded beyond the starting stage. Further work is needed to elucidate the observed effects in such case.

AIR-DRY RAW JUTE FILAMENTS (Mechanically conditioned)

(μ - Mass per unit length ($\times 10^{-6}$ gm./cm.))



[A] Lower Values of μ

[B] Higher Values of μ

Fig. 4.

WET JUTE FILAMENT

(No Mechanical Conditioning)

μ - - Mass per unit length ($\times 10^{-3}$ gm./cm)

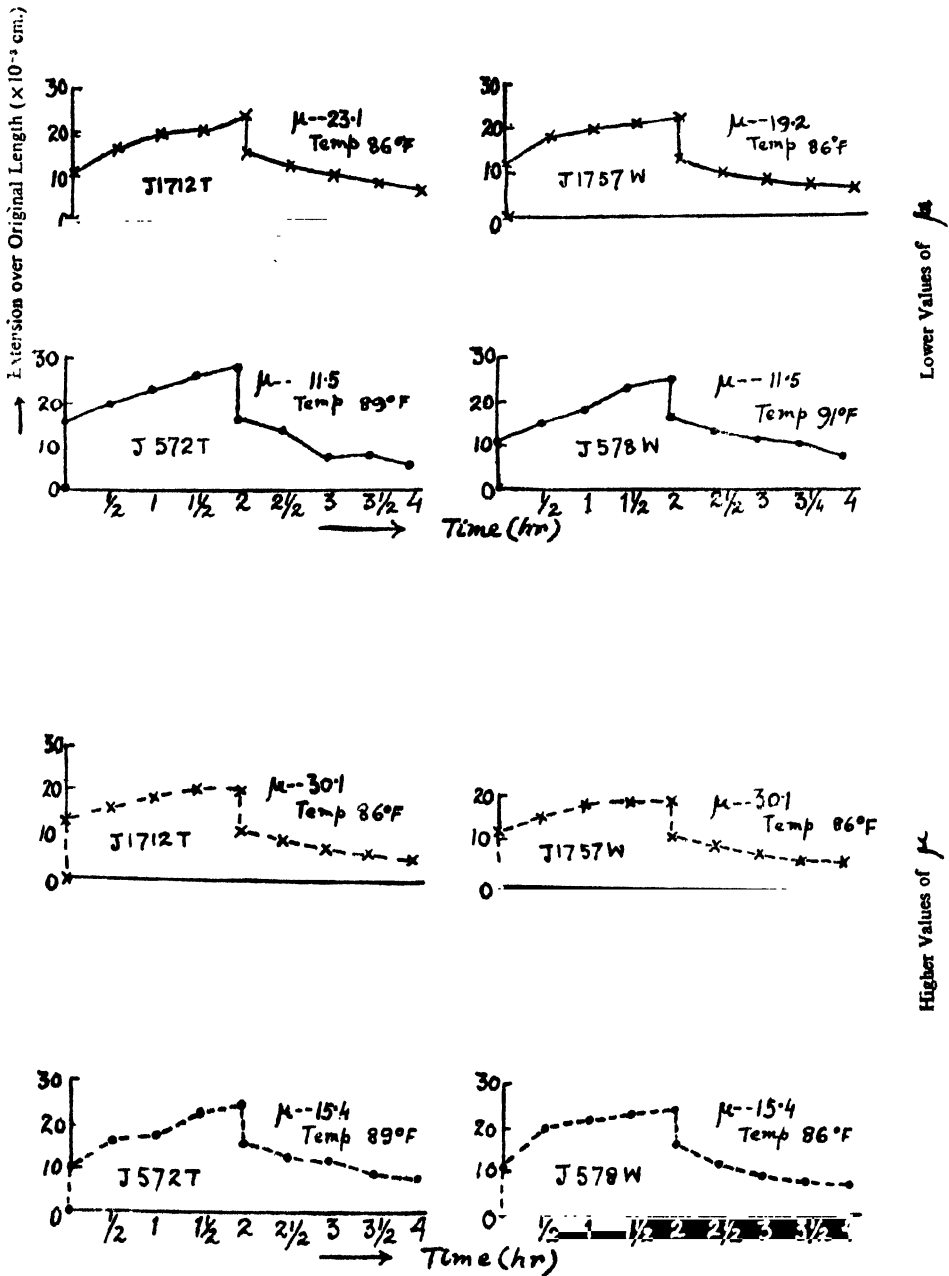


Fig. 5.

AIR-DRY JUTE FILAMENT

EXTENSION —●—
CONTRACTION ○---○

μ = Mass per unit length ($\times 10^{-3}$ gm./cm.)
 t_1 = Time of extension
 t_2 = Time of contraction

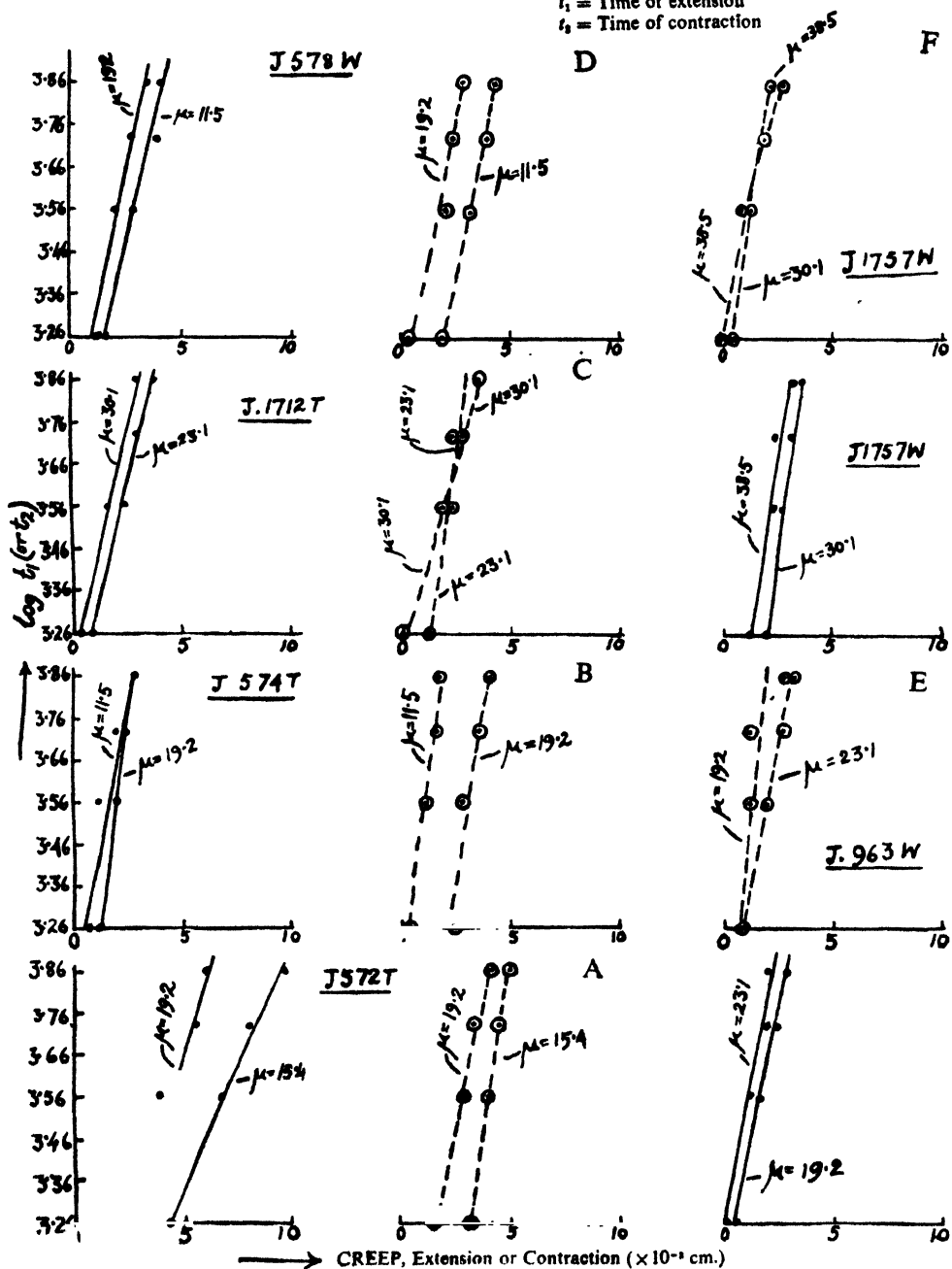


Fig. 6.

WET JUTE FILAMENT

EXTENSION ———●——— μ , t_1 , $t_2 \rightarrow$ as in Fig. 5.
 CONTRACTION ---○--- μ -Low μ -High

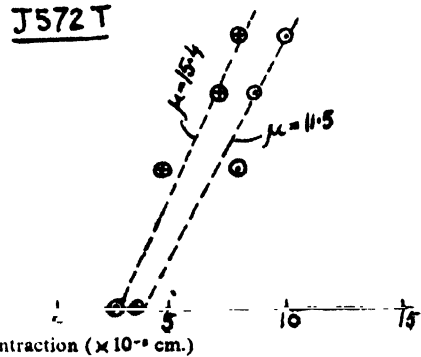
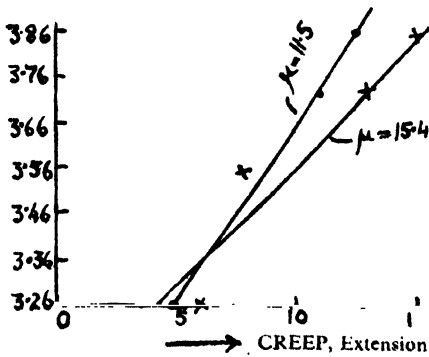
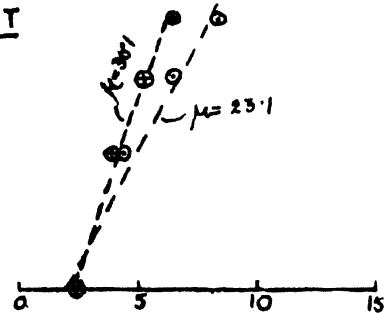
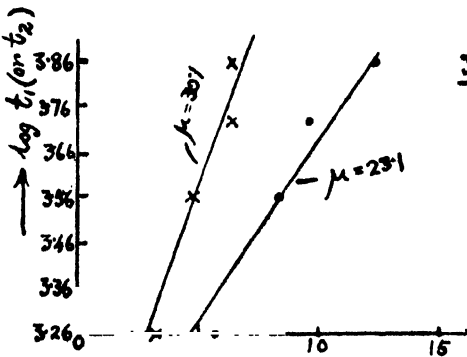
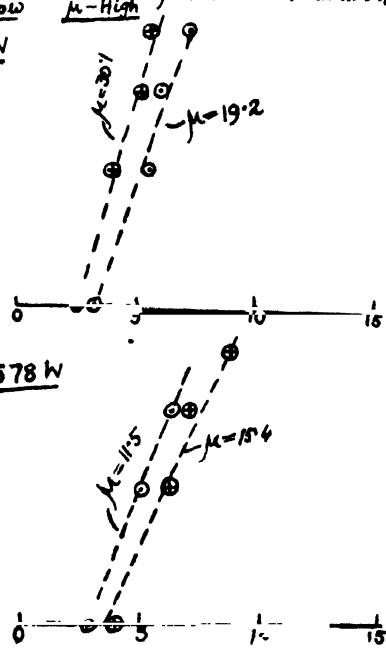
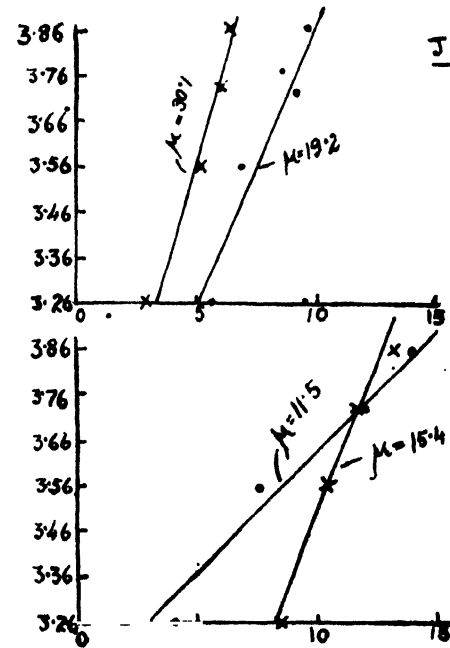


Fig. 7.

The creep and other changes in the air-dry as well as the wet conditions are shown graphically in Fig. 4 and Fig. 5. The graphs are of well-known type. One most striking thing about the figures, however, is the variable rate exhibited by some of the wet filaments. The cause cannot be definitely indicated. But it is possible that a little vibration caused by the falling drops of water, as they dropped on the lower eyelet, may have produced the effect. The fact that the rate variation is absent in the case of the heavier filaments of the same jute, also points to this being probably the reason. Fig. 6 and Fig. 7 for the air-dry and the wet jute filaments respectively exhibit a rectilinear relationship between log (time) and either the creep or the recovery. There is thus very good agreement with the theory.

It may be noted that in the case of some varieties in the air-dry state and some in the wet state, an anomalous behaviour which records, wholly or partially lower extension or contraction for the gravimetrically finer filaments, occurs. It is hazardous in the present state of knowledge to offer any categorical explanation of this phenomenon. Tentatively, however, it may be suggested that the cause may lie with the variations of diameter of filaments along the length.

6. SUMMARY.

By direct observation, the instantaneous changes on loading and unloading, the primary creep and the creep recovery of single filaments of various jute varieties were examined in both dry and wet condition. The rapidity of recovery of creep which has been developed in dry state, on wetting the filament, was also determined. A qualitative study of the behaviour in relation to the well-known visco-elastic theory of high polymers as well as an explanation of observed peculiarities in respect of creep in the light of mechanical and thermodynamical principles have been attempted. The following characteristics have been noted. (1) When a wet filament has been loaded and unloaded, a large lag between the instantaneous extension and contraction, is observed. (2) Recovery from creep in air-dry condition is practically complete in mechanically conditioned filaments, within the same time as under load. (3) Recovery from creep of wet filaments shows considerable lag. (4) Recovery of wet filament from creep is intermediate in value between the recovery in air-dry state and the creep in the wet state. (5) Filaments stretched without previous mechanical conditioning for a long period (18 hours) in air-dry state, and allowed preliminary to recover in the same state for an hour, on 15 minutes subsequent wetting, not only showed full recovery, but were even found to contract beyond the initial (test) length. (6) There is apparently some dissipation of energy in going through a loading-creep-unloading-recovery cycle. (7) Creep and recovery of jute exhibit a practically linear relationship with the logarithm of time.

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* Collected from H. Leaderman's work (Leaderman, 1943).

8. APPENDICES.

A—Creep and Recovery of Different Jute Varieties in Air-dry state.

Jute Ref. No.	Q.R. (Standard 10 lb. heys. wett yarn)	Density, ρ (gm./ c.c.)	Filament, mm. per unit length, μ (to $\times 10^{-6}$ gm./cm.)	Extension under load (10-3 cm.)					Temp. °F.	R.H. %	Contraction on removing load (10-3 cm.)					Temp. °F.	R.H. %	(Calculated Young's Modulus, ν (10 ¹¹ dynes/cm. ²)
				Time since start (hr.)							Time since unloading (hr.)							
				0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2			0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2			
J572T	114	1.387	15.4	48.0	52.4	54.8	56.0	57.6	85	84	48.0	51.2	52.0	52.4	52.8	85	84	0.405
J574T	126	1.374	14.2	35.6	38.4	39.6	41.2	41.6	87	77	31.2	32.8	34.0	34.4	35.2	87	77	0.438
J574T	126	1.374	11.5	29.2	30.0	30.4	31.2	32.0	78	73	27.6	28.0	28.8	29.2	29.2	78	73	0.883
J1712T	87	1.383	19.2	14.4	15.6	16.4	16.8	17.2	78	75	11.2	13.6	14.0	14.8	15.2	78	75	1.073
J578W	96	1.367	23.1	12.8	13.6	15.2	15.6	16.4	82	64	10.4	11.6	12.4	12.8	14.0	82	64	1.009
J578W	96	1.367	30.1	9.6	10.0	11.2	12.4	12.4	84	70	7.2	7.2	9.6	10.0	10.8	84	70	1.000
J578W	96	1.367	11.5	28.0	29.6	30.8	32.0	32.0	84	66	25.2	27.2	28.4	29.2	29.6	84	66	0.916
J963W	90	1.334	19.2	9.6	10.8	11.6	12.4	13.2	80	59	7.6	8.0	9.6	10.0	10.4	80	59	1.601
J963W	90	1.334	19.2	12.4	12.8	14.0	14.8	15.2	79	74	10.8	11.6	12.0	12.0	13.6	79	74	1.210
J1757W	63	1.368	23.1	9.6	9.6	10.8	11.6	11.6	81	69	5.6	6.4	7.6	8.4	8.8	81	69	1.298
J1757W	63	1.368	30.1	10.0	12.0	12.8	13.2	13.6	87	71	5.8	9.2	9.6	10.4	11.2	87	71	0.958
J1757W	63	1.368	38.5	7.6	8.8	10.0	10.0	10.8	85	75	6.4	6.4	7.6	8.0	8.4	85	75	1.000

Note: Test Length, $l = 10$ cm.

Testing Load = 1.80 gm.

Load for Mechanical Contraction = 4.62 gms.

B—Creep and Recovery of Different Jute Varieties in Wet Condition.

Jute Ref. No.	Q. R. (Stand- ard 10 lb. hess. weft yarn)	Density, ρ (gm./c.c.)	Mass of Air-dry filament per unit length, μ (10-6 gm./cm).	Extension under load (10-3 cm.)					Temp. °F.	Contraction on removing load (10-3 cm.)					Temp. °F.
				Time since start (hr.)						Time since unloading (hr.)					
				0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2		0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	
J572T ..	114	1.387	11.5	15.6	20.4	23.2	26.4	28.0	89	11.6	14.4	19.6	20.4	21.6	89
			15.4	10.4	16.4	18.0	23.2	25.2	88	8.8	12.4	13.6	16.0	16.8	89
J1712T ..	87	1.383	23.1	10.8	16.4	19.2	20.4	23.2	86	8.4	10.8	12.8	14.8	16.8	86
			30.1	13.2	16.4	18.0	19.6	19.6	85	8.4	10.8	12.4	13.6	14.8	86
J578W ..	96	1.367	11.5	10.8	14.8	18.4	22.8	24.8	90	8.8	11.6	14.0	15.2	17.6	91
			15.4	11.2	19.6	21.6	22.8	24.4	86	8.8	12.8	15.2	16.0	17.6	86
J1757W	63	1.368	19.2	12.0	17.6	18.8	21.2	21.6	86	8.4	11.6	14.0	14.4	15.6	86
			30.1	12.4	15.2	17.6	18.4	18.8	85	7.6	10.0	11.6	12.8	13.2	86

Note: Test Length, $l = 10$ cms.

Testing load = 1.80 gm.

No Mechanical Conditioning.

ON A FLUID MOTION WITH A SPHERICAL BOUNDARY

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(Communicated by Dr. R. S. Varma, F.N.I.)

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• 1. INTRODUCTION.

In the year 1940, (Ballabh 1940) I had derived the general conditions under which one fluid motion, can be superimposed on another motion such that the velocity of the resulting flow is the vector sum of the velocities of separate flows. If one motion is a constant streaming represented by the vector $Q = Ui + Vj + Wk$, the conditions reduce to the vector equations

$$Q \cdot \nabla \xi = 0, \quad Q \cdot \nabla \eta = 0, \quad Q \cdot \nabla \zeta = 0. \quad \dots \quad (1)$$

where ξ, η, ζ are the vorticity components of the flow superposable on Q .

The analysis of fluid motion developed in this manner has opened a new field of investigation in hydrodynamics and furnished a method of finding exact solutions of Stokes-Navier equations of viscous fluid motion where the inertia terms are generally omitted to effect simplification.

In the present paper we shall obtain the general types of flows superposable on a constant streaming $(U, 0, 0)$, the boundary being a sphere of finite radius in a viscous or non-viscous liquid; and study a particular case of exact solution, which we believe is new.

2. GENERAL SOLUTION.

The interesting cases of problems (Lamb 1932) where the boundary conditions have relation to spherical surfaces belong either to the class

$$xu + yr + zw = 0, \quad \dots \quad (2.1)$$

or to the class

$$x\xi + y\eta + z\zeta = 0, \quad \dots \quad (2.2)$$

where ξ, η, ζ are the vorticity components of a fluid motion of which the velocity components are u, v, w .

If the fluid motion be superposable on a constant streaming $(U, 0, 0)$, it follows from equations (1) that ξ, η, ζ must all be independent of x .

Further, if the requirement (2.2) is to be fulfilled, we have $\xi = 0$ identically so that the vortex lines must be circles about the axis of x , which is the case when the x -axis is the axis of symmetry for the motion.

Equation (2.2) now reduces to

$$y\eta + z\zeta = 0,$$

which with

$$\frac{\partial \eta}{\partial y} + \frac{\partial \zeta}{\partial z} = 0 \quad * \quad \text{gives}$$

$$\left. \begin{aligned} \eta &= F(y^2 + z^2) \\ \zeta &= -y F(y^2 + z^2) \end{aligned} \right\} \quad \dots \quad (2.3)$$

The vorticity is, therefore, a function of the distance from the axis of x .

* This follows from the equality $\text{div}(\text{curl velocity vector}) = 0$.

It may be worth while examining whether a fluid motion of which the vortex lines are circles about the axis of x is superposable on a constant streaming $(U, 0, 0)$.

We have

$$\xi = 0, \quad y\eta + z\zeta = 0,$$

and these with

$$\frac{\partial \eta}{\partial y} + \frac{\partial \zeta}{\partial z} = 0$$

give

$$\eta = zf(y^2 + z^2, x)$$

$$\zeta = -yf(y^2 + z^2, x),$$

which, in general, is not superposable on $(U, 0, 0)$.

If $\xi = 0$, and η and ζ have the values (2.3), we have

$$\xi = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} = 0 \quad \dots \quad (2.4)$$

$$\eta = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = zF(Y) \quad \dots \quad (2.5)$$

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = -yF(Y) \quad \dots \quad (2.6)$$

and the continuity condition

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad \dots \quad (2.7)$$

where $Y = y^2 + z^2$.

Eliminating v from (2.6) and (2.7),

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 w}{\partial x \partial z} = F(Y) + 2y^2 F'(Y).$$

Eliminating w with the help of (2.5),

$$\nabla^2 u = 2F(Y) + 2YF'(Y),$$

∇^2 being the operator

$$\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}.$$

Again, eliminating u and w from (2.4), (2.6) and (2.7),

$$\nabla^2 v = 0.$$

Similarly

$$\nabla^2 w = 0.$$

The velocity components of a fluid motion of which the vortex lines are circles about the axis of x and which is superposable on $(U, 0, 0)$ are thus seen to be solutions of the equations

$$\nabla^2 u = 2F(Y) + 2YF'(Y)$$

$$\nabla^2(v, w) = 0.$$

3. A PARTICULAR CASE.

Let us examine the steady symmetric flow

$$\left. \begin{aligned} u &= -\frac{1}{2} U \left(\frac{a}{r} \right)^3 + \frac{3Ux^2}{2a^2} \left\{ \left(\frac{a}{r} \right)^5 + 1 \right\} + \frac{3U}{2a^2} f(Y) \\ v &= \frac{3Uxy}{2a^2} \left\{ \left(\frac{a}{r} \right)^5 - 1 \right\} \\ w &= \frac{3Uxz}{2a^2} \left\{ \left(\frac{a}{r} \right)^5 - 1 \right\} \end{aligned} \right\} \dots \dots (3.1)$$

This gives

$$\xi = 0$$

$$\eta = \frac{3U}{2a^2} z(1+2f')$$

$$\zeta = -\frac{3U}{2a^2} y(1+2f')$$

$$\nabla^2 u = \frac{3U}{a^2} (1+2f'+2Yf'')$$

$$\nabla^2 v = 0, \quad \nabla^2 w = 0,$$

so that the fluid motion given by (3.1) is superposable on $(U, 0, 0)$.

The conditions of integrability (Lamb 1932) of the equations of motion of (u, v, w) are

$$\eta \frac{\partial u}{\partial y} + \zeta \frac{\partial u}{\partial z} = 0 \quad \dots \dots \dots (3.2)$$

$$\eta \frac{\partial v}{\partial y} + \zeta \frac{\partial v}{\partial z} + v \nabla^2 \eta = r \frac{\partial \eta}{\partial y} + w \frac{\partial \eta}{\partial z} \quad \dots \dots \dots (3.3)$$

$$\eta \frac{\partial w}{\partial y} + \zeta \frac{\partial w}{\partial z} + v \nabla^2 \zeta = r \frac{\partial \zeta}{\partial y} + w \frac{\partial \zeta}{\partial z} \quad \dots \dots \dots (3.4)$$

Equation (3.2) is identically satisfied for any f . Now, we have

$$\nabla^2 \eta = \frac{6U}{a^2} z(4f''+2Yf''')$$

$$\eta \frac{\partial v}{\partial y} + \zeta \frac{\partial v}{\partial z} = \left(\frac{3U}{2a^2} \right)^2 xz(1+2f') \left\{ \left(\frac{a}{r} \right)^5 - 1 \right\}$$

$$r \frac{\partial \eta}{\partial y} + w \frac{\partial \eta}{\partial z} = \left(\frac{3U}{2a^2} \right)^2 xz(1+2f'+4Yf'') \left\{ \left(\frac{a}{r} \right)^5 - 1 \right\},$$

so that equation (3.3) is true only if $f'' = 0$,

i.e., if

$$f = A(y^2+z^2) + B,$$

where A and B are constants.

It is easy to see that equation (3.4) is also satisfied for this value of f .

If the boundary for the viscous fluid motion is a sphere of radius a , we have

$$A = 2, \quad B = -\frac{5a^2}{3},$$

and the solution is

$$\left. \begin{aligned} u &= -\frac{1}{2} U \left(\frac{a}{r}\right)^3 + \frac{3}{2} U \frac{x^2}{a^2} \left\{ \left(\frac{a}{r}\right)^5 + 1 \right\} + \frac{3U}{a^2} (r^2 - x^2) - \frac{5}{2} U \\ v &= \frac{3}{2} U \frac{xy}{a^2} \left\{ \left(\frac{a}{r}\right)^5 - 1 \right\} \\ w &= \frac{3}{2} U \frac{xz}{a^2} \left\{ \left(\frac{a}{r}\right)^5 - 1 \right\} \end{aligned} \right\} \quad \dots \quad (3.5)$$

This is an *exact solution* of the equations of motion of a viscous liquid valid within a spherical boundary of radius a .

Solution (3.5) can be written as

$$u = u_1 + u_2$$

$$v = v_1 + v_2$$

$$w = w_1 + w_2,$$

where

$$u_1 = -\frac{1}{2} U \left(\frac{a}{r}\right)^3 + \frac{3}{2} U \frac{x^2}{a^2} \left(\frac{a}{r}\right)^5$$

$$v_1 = \frac{3}{2} U \frac{xy}{a^2} \left(\frac{a}{r}\right)^5$$

$$w_1 = \frac{3}{2} U \frac{xz}{a^2} \left(\frac{a}{r}\right)^5$$

and

$$u_2 = \frac{3U}{2a^2} (2r^2 - x^2) - \frac{5}{2} U$$

$$v_2 = -\frac{3}{2} U \frac{xy}{a^2}$$

$$w_2 = -\frac{3}{2} U \frac{xz}{a^2}.$$

(u_1, v_1, w_1) is the well-known irrotational solution for a sphere of radius a moving with velocity U in the direction of the x -axis in a non-viscous homogeneous incompressible fluid, and (u_2, v_2, w_2) is a rotational solution of the equations of motion self-superposable as well as superposable on (u_1, v_1, w_1) .

In a non-viscous homogeneous incompressible fluid (u_2, v_2, w_2) represents a possible form of rotational motion when a sphere of radius a moves with velocity $-U$ in the direction of x -axis.

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MALLOPHAGA (AMBLYCERA) INFESTING BIRDS IN THE PANJAB (INDIA).¹

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(Communicated by Dr. Hem Singh Pruthi, F.N.I.)

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¹ 'Mallophaga (Ischnocera) infesting birds in the Panjab (India)' has been published in the Proceedings of the National Institute of Sciences of India, Vol. XIII, No. 6, pp. 253-303 (1947).

This work was carried out during 1934-1936 and 1940-1942 in the Entomological Laboratory, Panjab Agricultural College, Lyallpur, and was finally prepared during 1936-37 and 1942-43 in the laboratory of the Imperial Entomologist, Imperial Agricultural Research Institute, New Delhi; but due to certain unavoidable circumstances it could not be presented for publication earlier.

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I. INTRODUCTION.

Kellogg and Paine (1914) obtained a collection of the Mallophaga from the Indian Museum, Calcutta, and published an account of these insects, a year later, Kellogg *et al.* (1915) supplemented this. Waterston (1928), Qadri (1935-39), Miss Clay and Meinertzhagen (1935-48), Sen (1942) and Atiquur-Rahman-Ansari (1943-47) have made further contributions to the study of the Indian Mallophaga.

A study of the feeding habits of the birds of the Panjab was taken in hand at the Panjab Agricultural College and Research Institute, Lyallpur, in 1926, and at the suggestion of Professor M. Afzal Husain, the then Entomologist to the Government of the Panjab, a collection of Avicolous Mallophaga was made from about one hundred different species of birds. The collection, although small, furnished fresh information on the distribution of several forms and it contained several species which were undescribed.

The types of all the new forms described here are provisionally deposited in the author's collection, until sufficient material is available for distribution to museums of standing and repute.

ACKNOWLEDGMENTS.

This work was undertaken at the suggestion of Professor M. Afzal Husain (formerly Vice-Chancellor, Panjab University). I express my gratitude to him for his instruction, help and encouragement. I owe a deep debt of gratitude to Dr. Hem Singh Pruthi, for his keen interest and valuable advice in this work. I tender my thanks to Dr. Khan Abdul Rahman (Entomologist, Agricultural College, Lyallpur) for placing the entire collection of the Mallophaga at my disposal. I am deeply indebted to Miss Theresa Clay (Department of Entomology, British Museum—Natural History—London), Dr. K. B. Lal (Entomologist, Agricultural College, Cawnpur) and Dr. M. S. Mani (St. John's College, Agra) for kindly going through several parts of the typescript and making useful suggestions. I desire to express my thanks to Miss Clay, Mr. Hopkins (Formerly Senior Entomologist (Medical) Kampala, Uganda), Dr. Cesari Conci (Istituto di Zoologia dell'Universitat, Geneva), Dr. Büttiker (Institut der ETH Universitässtrasse, Zurich) for assistance in sending me some of the original papers on the group. My thanks are also due to my wife, Zohra, for her kind assistance in collecting Mallophaga from some birds. She also relieved me of much of the drudgery of the mechanical preparation of the paper. Without this co-operation the investigation recorded could never have been completed.

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II. SYSTEMATIC ACCOUNT.

AMBLYCERA¹

1896, *Amblycera*, Kellogg, *Proc. Calif. Acad. Sci.*, VI (2), p. 68.

Nitzsch (1818) named this group Liotheidae with two genera, viz., *Gyropus* (with one clawed-tarsi, exclusively found upon mammals) and *Liotheum* (with two-clawed tarsi, exclusively infesting birds). He further divided the latter genus into six sub-genera, viz., *Eureum*, *Læmobothrium*, *Physostomum*, *Trinoton*, *Colpocephalum*, and *Menopon*.

¹ *Amblys*: blunt, *Ceras*: horn. Mallophaga in which the antennae are capitate or swollen towards the free end, and when in repose largely concealed in lateral longitudinal excavations or antennal capsules, which sometimes are bulbous.

Kellogg (1896) adopted the Nitzschian classification in all essentials, with the difference that his families were raised to sub-orders, genera to families and sub-genera to genera. He also added several new genera to the list.

He created the sub-order Amblycera, and divided it into two families: Gyropidae (tarsi with one claw, exclusively infesting mammals) and Liotheidae (tarsi with two claws, exclusively infesting birds, except *Boopis* spp.). The latter family was further sub-divided into nine genera, i.e., *Colpocephalum* Nitzsch, *Boopis* Piaget, *Trinoton* Nitzsch, *Laemobothrion* Nitzsch, *Physostomum* Nitzsch, *Eureum* Nitzsch, *Menopon* Nitzsch, *Nitzschia* Denny and *Ancistrana* Westwood.

Several of these genera include widely differing forms. For instance the species of the genera *Colpocephalum* Nitzsch and *Menopon* Nitzsch are very loosely held together. Splitting of unwieldy genera has started and the status of certain genera has been raised to families. Harrison (1916-17) recognized four families and six sub-families, while Ewing (1926) recognized five families and five sub-families.

Today the bird-infesting species are generally grouped into three families, viz., Ricinidae Neumann, Laemobothriidae Mjöberg and Menoponidae Mjöberg. The latter family has, however, been further split into three avicolous sub-families namely Menoponinae Harrison, Ancistroninae Harrison and Menacanthinae Eichler. The number of described genera has increased very rapidly in recent years.

The species belonging to families Laemobothriidae and Menoponidae are presented in this paper. The table given below is based on the works of various investigators and will be found useful in recognizing genera dealt with in this paper.

TENTATIVE KEY TO FAMILIES, SUB-FAMILIES AND GENERA OF BIRD-INFESTING AMBLYCERA.

1. Antennae lying in grooves at the sides of head; abdomen always with lateral notches at the junction of different segments. Family: MENOPONIDAE. 2
- Antennae situated in bulbous capsules which open ventrally and constitute conspicuous lateral swellings on the head; abdomen without any lateral notches at the junction of different segments. Family: LAEMOBOTHRIDAE. 20
2. Forehead provided with a ventral spinous or uncinate process, arising from a position behind each palpus. Sub-family: MENACANTHINAE. 3
- Forehead without such characters. 6
3. Head squat, extremely broad, being more or less twice as wide across the temples as long, ocular slit present (on Columbæ). *Columbimenopon* gen. nov.
- Head less than twice as long as broad, temporal region of head much broader than forehead and prothorax. 4
4. Oesophageal sclerite well developed, tergites with one or two rows of setae (on Galliformes). *Uchida* Ewing (1930)
- Oesophageal sclerite vestigial and modified. 5
5. Forehead narrow in front, greatly reduced; mandibles situated almost near the anterior margin; tergites with two transverse rows of setae (on Galliformes). *Eomenacanthus* Uchida (1926)
- Forehead broadly rounded in front; mandibles situated a short distance behind the anterior margin; tergites with a transverse row of setae (on Passeriformes). *Menacanthus* Neumann (1912)
6. Posterior femora and certain abdominal sternites with combs of short and stiff spines. Sub-family: COLPOCEPHALINAE. 7
- Posterior femora and abdominal sternite without combs of spines. Sub-family: MENOPONINAE. 14
7. 2-3 fringes of stout setae curving upwards around the sides of the VIII abdominal sternite. 8
- Fringes of stout recurved setae wanting. 9
8. Forehead flatly rounded, truncate; ocular emargination acute; ventral surface of posterior femora and III abdominal sternite with 4-5 combs of short and stiff hairs (on Galliformes). *Galliferrisia* gen. nov.
- Forehead convex; ocular emargination squarish; posterior femora with three combs of short stiff spines on the ventral surface; two such combs on each side of the III abdominal sternite. *Colpocephalum* Nitzsch (1818)

9. Ocular emargination present, not very deep; ocular slit present.....10
Ocular emargination deep; ocular slit wanting.....12
10. Three combs of stiff and short setae on each side of third abdominal sternite.....11
Two combs of stiff and short setae on each side of third abdominal sternite; posterior femora with three combs of stiff and short setae on ventral surface (on Herodiones).....*Pseudocolpocephalum* Qadri (1936)
11. Three combs on each side of fourth abdominal sternite; posterior femora with four or five combs and a group of irregularly scattered hairs on the ventral surface (on Cuculiformes).....*Cuculiphilus* Uchida (1926)
Fourth abdominal sternite without combs of spines; posterior femora with three combs of setae (on Strigiformes).....*Uluoecus* subg. nov.
12. Two combs of stiff and short setae on each side of third and fourth abdominal sternites; posterior femora with four combs and a group of irregularly scattered hairs on the ventral surface (on Herodiones).....*Ardeiphilus* Bedford (1939)
Two combs of stiff and short setae on each side of III abdominal sternite; IV sternite without such combs of setae; posterior femora with three ventral combs of setae.....13
13. Genitalia of male with a chitinous structure near the apex of the basal plate, usually complex.....*Allocolpocephalum* Qadri (1939)
Genitalia of male without a chitinous structure near the apex of the basal plate (on Picidae).....*Picusphilus* subgen. nov.
14. Meso- and meta-thorax fused.....15
Meso- and meta-thorax distinctly separated.....16
15. Forehead with distinct slit in front of eyes; gular region without gular plate.....*Menopon* Nitzsch (1818)
Forehead truncate, with shallow or deep notch in front of the eyes; posterior margin of forehead straight, meeting the temples at right angles; gular region with well chitinized quadrate plate; dark species, (on Pterocletes).....*Neomenopon* Bedford (1920)
16. Thorax very large and heavily chitinized, meso- and meta-thorax divided by a distinct suture none of them similar in shape to the abdominal segments; legs short, stout and heavy (on Anatidae).....*Trinoton* Nitzsch (1918)
Thorax normal; meso- and meta-thorax separated by indistinct suture, both somewhat similar to abdominal segments.....17
17. Forehead with a distinct notch in the lateral margin, just before the eyes; femoral and sternal patches small, composed of spines which are as large as those constituting the general chaetotaxy and sometimes merging with it (on Charadriiformes).....*Actornithophilus* Ferris (1916)
Lateral margins of forehead continuous with the eyes.....18
18. Head less than twice as broad as long; second abdominal sternite usually beset on each side with a group of heavy, belonoid spines on well-formed callosity; certain abdominal sternites and ventral face of posterior femora with indistinct patches of spines; male genitalia with moderately long basal plate, continuous distally with a broad rounded lamina at the base of which the stout apically recurved parameres are set.....19
Head twice as broad as long, sometimes more; II abdominal sternite without a group of heavy spines; sternites IV-VI with setae, more numerous on lateral margins; posterior femora with fine setae on venter, usually not sufficient to form a brush; male genitalia with basal plate short, narrow in front, gradually broadening towards apex, where it expands; parameres present (on Charadriiformes).....*Austromenopon* Bedford (1939)
19. Genital armature with complex chitinous structure near the apex of the basal plate (on Passeriformes).....*Myrsidea* Waterston (1950)
Genital armature without chitinous structure near the apex of the basal plate (on Coraciiformes).....*Alcediniphilus* gen. nov.
20. Clypeus not excavated or concave (on Accipiteres).....*Laemobothrion* Nitzsch (1918)

Sub-family: MENACANTHINAE

COLUMBIMENOPON gen. nov.

Small, wide-bodied form with the following diagnostic characters:—

Head almost twice as broad as long; forehead flatly rounded in front with a minute median notch; lateral margins without ocular emargination, but with narrow slit in front of well developed eyes; ocular fleck well marked; temples slightly expanded, rounded marginally; ventrum with well built skeleton to support mandibles, continuous to the anterior clypeal margin; mandibles situated a short distance behind the anterior margin; antennal fossae backed by chitinized area; antennae 4-segmented; a backwardly directed rectate, recumbant, moderately long, peg-like, spinous process arising near the base of each palpus; oesophageal

sclerite and glands present; gular plate not well chitinized, quadrate, furnished with lateral hairs. Pro-thorax well built, winged; meso-thorax narrow, indistinctly separated; meta-thorax short; sternal plates well developed. Legs normal, third femora with distinct patches of setae. Abdomen short, orbicular, last segment entire, flatly rounded; ventral surface with patch of fine setae on III, IV, and V sternites.

Exhibit sexual dimorphism, last segment in male being devoid of fringe of hairs. Genitalia simple, basal plate short, furnishing short slender paramere and a quadrate, flatly rounded lamina. The paramere with the distal end slightly curved outward.

This genus is closely allied to *Menacanthus* Neumann (1912) and *Uchida* Ewing (1930), from both of which it can be distinguished by the shape of the head, ventral patches of hairs on III femora and III-V abdominal sternites.

This genus is apparently confined to pigeons and doves (Columbae).

Type of the genus: *Columbimenopon modestus* sp. nov. (*vide infra*) ex the Indian Ring Dove, *Streptopelia d. decaocta* (Frival.).

1. *Columbimenopon modestus* sp. nov.

Female (Text-fig. 1a): pale yellow with broad body, almost spherical abdomen.

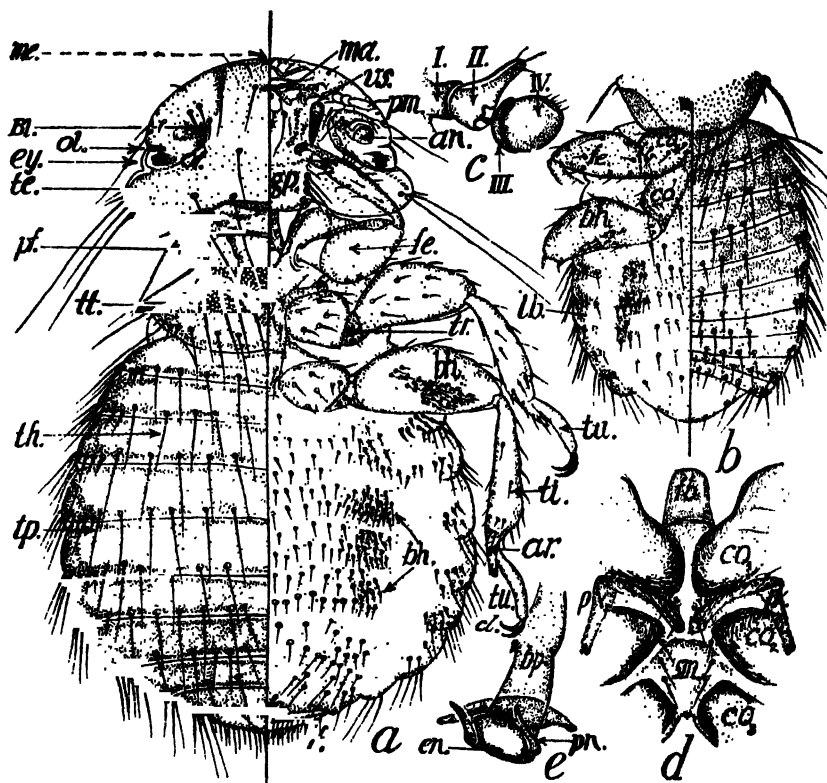
Head very broad, almost twice as broad as long; pre-antennal region narrow; front broadly rounded, with a minute median notch, furnished with dorsal and ventral hairs as shown in text-figure; ocular slit narrow; eyes well developed, ocular fleck trilobed; ocular fringe obsolete, inferior, not projecting laterally; temples narrow, slightly expanded, margins rounded, bearing two short and three long hairs; occipital margin sinuous, edged with narrow band, bearing two long hairs on each half; vertex with one long hair; two long, one short and two minute hairs on each side of the dorsum of head. Ventrum with well developed skeleton to support mandibles, reaching as far as on each side of clypeal region; peg-like process arising near the base of palpi; clypeus narrow; mandible weak; gular plate squarish not well chitinized, bearing four hairs on each side. Antennae exhibit very outstanding characters (Text-fig. 1c), segment I short, squat, on which fits exactly the pedicel which is more or less of the shape of an antique Egyptian lampion, one side produced into lobe or arm (antennule), extending latero-apically far forwards, antennule being larger than the body of the joint; segment III calyciform, with shallow cup and short peduncle, which is immediately inserted in the well marked depression of lampad segment II; segment IV irregularly spherical, resting obliquely in shallow cavity of the calyx; apical depression well defined.

Pro-thorax large, expanded; lateral angles obtuse, with a spine and long hair; posterior lateral margin straight, practically confluent with the posterior margin, strongly convergent, each bearing two long and two minute setae; posterior margin convex and bears three long hairs on each side of a median protuberance; transverse bar and lateral bands well developed, a short spine on the bar-end. Meso-thorax narrow, suture indistinct. Meta-thorax short, trapezoidal; lateral margin diverging posteriorly with two minute spines; lateral angles produced with a long and several short spines; posterior margin convexo-concave, with four long hairs and two spines on each half, disposed of as shown in figure. Legs well built, third femora with definite patch of short hairs. Sternal plates (Text-fig. 1d) well formed.

Abdomen short, broad, orbicular, almost round; segments projecting, dorsum with a transverse row of long hairs to each segment, of which lateral 2-3 becoming spinous; last segment fringed with fine hairs. Ventrum medially hairy; third to fifth sternites with group of hairs on each end, merging more or less with general chaetotaxy; pleural plates with spinous hairs.

Male (Text-fig. 1b): similar to female, but smaller and chaetotaxy more scarce; last segment parabolic with four small marginal hairs. Genitalia (Text-fig. 1e)

simple; basal plate short, faintly chitinated, continuous distally with a squarish flatly rounded lamina; at each side of which is a slender, short paramere with slightly curved outward distal end.



TEXT-FIG. 1. *Columbimenopon modestus*, sp. nov.: (a) dorsal and ventral aspects of female, (b) ventral and dorsal aspects of thorax and abdomen of male, (c) antenna of female (enlarged), (d) ventral aspect of thorax (enlarged), and (e) male genital armature (enlarged). (For lettering and explanation of figures see page 201.)

Measurements (mm.) of Columbimenopon modestus sp. nov.

	Female (Holotype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.426	.....	1.025	.....
Head	0.293	0.560	0.266	0.426
Pro-thorax	0.160	0.360	0.133	0.293
Ptero-thorax	0.160	0.440	0.106	0.346
Abdomen	0.813	0.729	0.520	0.453
Head-index ¹ (breadth : length) ..	1.91		1.601	

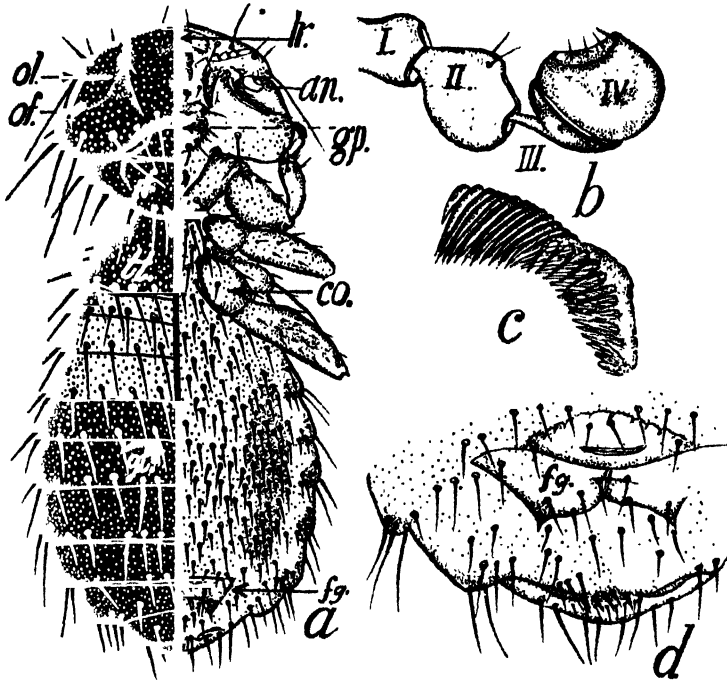
¹ Head-index is the proportion of the breadth to the length of the head (Clay, 1938 and 1940).

Holotype: A female, *Allotype*: A male; both from Lyallpur, 12. viii. 1929, ex the Indian Ring-Dove, *Streptopelia d. decaocta* (Frival.); on slide No. MA. 049. *Paratypes*: 3 females in spirit (same data as above).

This species does not resemble any species so far described from doves and pigeons.

2. *Columbimenopon chanabensis* sp. nov.

Female (Text-fig. 2a): body yellowish-pale, with pale-brownish markings on head.



TEXT-FIG. 2. *Columbimenopon chanabensis*, sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) gastric teeth (enlarged), and (d) genital plate on VIII abdominal sternite (enlarged).

Head extremely broad, being slightly more than twice as wide across the temples as long; forehead flatly rounded in front, a minute hair on each side of the middle; then two minute hairs, one short hair and a long hair on the lateral margin, which is continuous to the eyes, with a narrow ocular slit; a long and a short hair on each side of the dorsum of head. Eyes large, fleck oblong with a minute spine. Temples rounded with one long, one short and two minute marginal hairs and a long submarginal hair. Occipital margin concave, bearing three long hairs on each half. Ventrum with yellowish-brown skeleton to support mandibles, continuous to the anterior clypeal region. Antennal fossae covered above by a transversely slitted expansion of head; ventral expansion reduced, narrow, backed up by a highly chitinized area. Antennae four-jointed (Text-fig. 2b); scape small, II joint irregularly pyriform, with narrow base inserted apically in segment I, outer margin slightly produced; third joint calyciform with very shallow cup and short and narrow peduncle which is immediately inserted in the well marked depression of segment II; segment IV spherical, resting in the shallow cavity of the calyx, latero-apical depression well defined, deep; visible chaetotaxy disposed of as in

figure. Spinous process arising from the base of each palpus, 0.055-0.060 mm. long. Gular region lightly chitinized, squarish, with four short lateral hairs, continuous anteriorly with chitinous framework giving articulation to mandibles. Oesophageal sclerite and glands well developed.

Pro-thorax large and winged; lateral angles acute, produced, each with a spine and a long hair; posterior lateral margin nearly straight, diverging posteriorly, practically continuous with the posterior margin, each with one short, one long and one fine hair; posterior margin convex with three long hairs on each side of a median cylindrical ridge; transverse band narrow, pale-yellow, distinct; lateral chitin bar pronounced, reaching as far as the scapular area. Meso-thorax narrow, lateral bands distinct, posterior suture indistinct. Meta-thorax trapezoidal, lateral margin slightly convex, with several spinous hairs; lateral angles produced with a long hair; posterior margin nearly straight with fine long hairs. Legs paler than thorax, marginal markings on femora and tibia narrow, spiny. Pro-sternum reduced, completely covered by the plate-like coxae of fore-legs; meso- and meta-sternites with several hairs.

Abdomen broadly elliptical, widest at the fifth segment; length of segment I shortest, that of II-VIII subequal, lateral margins of each with 2-3 spines; posterior lateral angles I-VII, each bearing two long hairs; posterior margins I-VII nearly straight, each bearing a submarginal row of 4-5 hairs on each half; segment VIII strongly concave posteriorly, bearing 4-5 hairs in the posterior angle and a hair on posterior margin; segment IX broadly rounded with six hairs on each posterior half. Ventral surface of each abdominal sternite bearing two or three transverse rows of short hairs. The most important feature is the occurrence of a complex chitinous structure on the VIII abdominal sternite, shown in figure (Text-fig. 2d). Gastric teeth present (Text-fig. 2c).

Male: not available.

Measurements (mm.) of Columbimenopon chanabensis sp. nov.

	Female (Holotype).		Female (Paratype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.484	....	1.532	....
Head	0.252	0.534	0.252	0.563
Pro-thorax	0.204	0.388	0.242	0.408
Ptero-thorax	0.155	0.417	0.165	0.446
Abdomen	0.873	0.631	0.873	0.534
Head-index	2.119		2.234	

Holotype: A female from Lyallpur, 1-ix-1930, on slide No. MA. 044, ex (?) the Himalayan Griffon Vulture, *Gyps himalayensis* Hume. *Paratype*: one female on slide No. MA. 044P (same data as above).

This parasite is probably a straggler and appears to have transferred itself from a pigeon or dove on which the host might have preyed prior to shooting or it might have reached this host from the game bag in which the bird was carried.

This species almost resembles *Columbimenopon modestus*, sp. nov. (*vide supra*), but from which it can be distinguished by differences in shape of antennae, chaetotaxy and in some characters of the posterior region of the abdomen.

3. *Columbimenopon* sp.

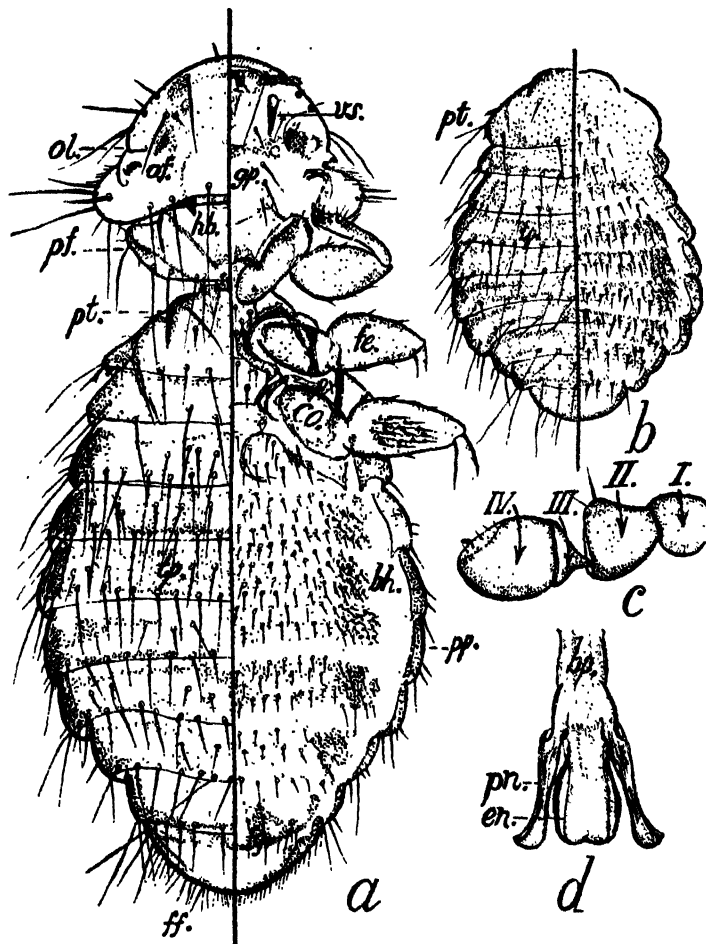
Two female specimens were collected from the Indian Blue Rock Pigeon, *Columba livia intermedia* Strick; shot in Lyallpur. The poor condition of these specimens

has made an exact determination impossible. However, it is apparent that the specimens are closely related, if not conspecific, with *Columbimenopon modestus*, sp. nov. (*vide supra*). It has been considered advisable to leave the exact identity until more material is available to me.

4. *Uchida abdominalis indicus* subsp. nov.

Piaget (1880) described *Menopon abdominalis* from the Grey Quail, *Coturnix c. coturnix* Linn. While the specimens before me agree fairly well with this species, differences, however, exist in the size of certain parts, general chaetotaxy of abdominal tergites, and the length of the hairs on the posterior margin of the last abdominal segment.

Female (Text-fig. 3a): body pale-brownish, with dark-brown markings on head, thorax and abdomen.



TEXT-FIG. 3. *Uchida abdominalis* var. *indicus* nov.: (a) dorsal and ventral aspects of female, (b) dorsal and ventral aspects of abdomen of male, (c) antenna of female (enlarged), and (d) male genital armature (enlarged).

Head broad, somewhat lunate in shape, front parabolic with a minute hair on each side of the middle; two short hairs and a long hair on each side, a long

and a fine hair in the lateral angle; a short and a long hair on the dorsum, and a long submarginal hair near the anterior frontal margin; ocular slit distinct; eyes large and flat, inconspicuously emarginated; ocular fleck irregularly oblong, bare; temples narrowly expanded, rounded, each with three long, two short and several minute submarginal hairs; occipital margin slightly concave, edget with dark-brown band, bearing three long hairs on each half. Ventral surfaced with highly chitinized framework, running forward to the anterior margin of the head, extending to the inner border of the antennal fossae, and continued downwards to the occipital margin; a central narrow bar in the gular region; gular plate quadrate, chitin thin, very lightly pigmented with four long lateral hairs; mandibles situated well towards the frontal margin; labrum almost touching the anterior clypeal margin. Antennal fossae deep; dorsal flap complete, with a narrow ocular slit; ventral flap half as broad as dorsal flap, with a comb of hairs on latero-posterior margin. Antennae 4-jointed (Text-fig. 3c), scape well developed; II joint pear-shaped; III joint calyciform; IV joint conical with excavated top which is furnished with sensory hairs. Spinous process moderately long, 0.075 mm. in length.

Pro-thorax large, expanded; lateral angles produced, rounded, each with a spine and a long hair; posterior lateral margin almost straight, each bearing a minute hair and a long posterior hair; posterior margin straight with four long hairs on each side; transverse band pale-yellow; longitudinal chitinous bar dark-brown. Meso-thorax rudimentary, lateral bands dark-brown, a long hair and a spine also present. Meta-thorax short, dorsally fused with the meso-thorax, broad; lateral margins very slightly concave, widely divergent posteriorly, each bearing two minute spines; posterior lateral angles with two long hairs; posterior margin almost straight, set with one spine and four long hairs. Legs short, pale, with narrow marginal markings and a few scattered hairs; ventral surface of hinder femora with a group of short, stiff hairs. Sternal plates well developed, pericoxal plates highly chitinized, chaetotaxy as shown in figure 3a.

Abdomen ovate, widest at the IV segment; length of the segments almost equal, but segment I slightly narrow; posterior angles projecting a little, each bearing two long hairs; posterior margin of segments I-V nearly straight, those of VI and VII concave laterally and convex in the middle; segments I and VIII with one row and segments II-VII with two transverse rows of hairs, last segment rounded, with a fringe of colourless hairs. Transverse bands distinct with clear intersegmental area, entire on segments I-VIII; segment IX with band along posterior margin; lateral bands slightly more pigmented, brown. Ventral surface of each abdominal sternite with three transverse rows of hairs; group of weak setae on each side of III-VII sternites, merging in transverse rows.

Male (Text-fig. 3b): similar to female, but size considerably small, last segment devoid of fringe of fine hairs. Genitalia (Text-fig. 3d) pale, but well chitinized, of the type common to the genus.

Measurements (mm.) of Uchida abdominalis indicus, subsp. nov.

	3 males.		3 females.	
	Length.	Breadth.	Length.	Breadth.
Total	1.163-1.290	.....	1.819-1.924	.....
Head	0.261-0.291	0.485-0.522	0.335-0.358	0.612-0.649
Pro-thorax	0.149-0.164	0.313-0.358	0.185-0.224	0.448-0.493
Ptero-thorax	0.119-0.171	0.371-0.425	0.201-0.238	0.559-0.642
Abdomen	0.619-0.701	0.485-0.559	1.119-1.157	0.859-0.970
Head-index	1.769-1.858		1.709-1.913	

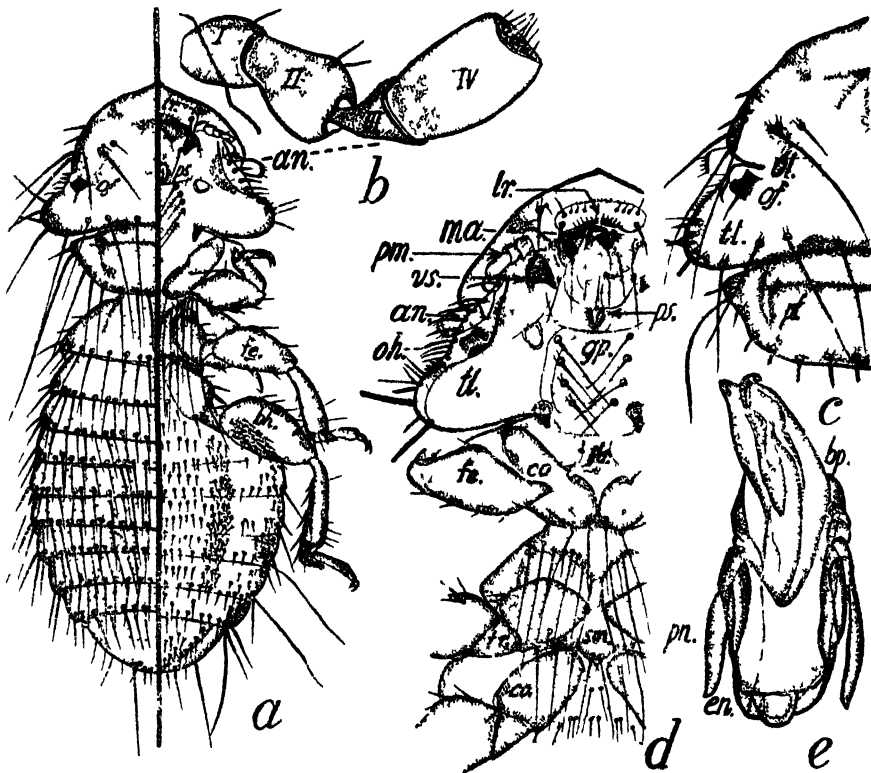
Piaget (1880) gave the measurements of *M abdominalis* (female) as 2.05 mm. $\times 0.97$ mm. The head-index calculated = 1.735

Holotype: A female on slide No. MA. 054 H, *Allotype*: A male on slide No MA 054 A; *Paratype*: two females and two males on slide No. MA. 054, all from Lyallpur, 11.ix.1931, ex the Common Grey Quail, *Coturnix c coturnix* (Linn)

5. *Uchida kalatitar*¹ sp. nov.

Male (Text-fig 4a): body broad, pale-yellow; with deep-yellow markings on head; pleural plates present but not well developed.

Head short; front broadly parabolic, slight angulation on meson with one minute hair on each side, two short and three long hairs on lateral angles; two short and a long hair on dorsum, situated a short distance above the ocular slit; ocular slit narrow, backed with brownish blotch. Eyes with double cornea; ocular fleck black, irregularly quadrate with a short posterior seta, ocular fringe distinct. Temples expanded, each lobe bearing five long and several short hairs. Occipital margin concave, narrowly edged with yellowish-brown band, bearing four long hairs on each side of the median line. On the ventrum, mandibles situated a short distance behind the anterior margin; labrum well built, bearing numerous hairs. Oesophageal sclerite and glands well developed; gular plate distinct, quadrate,



TEXT FIG 4. *Uchida kalatitar* sp. nov.: (a) dorsal and ventral aspects of male, (b) antenna of male (enlarged), (c) dorsal aspect of head and pro-thorax of male (enlarged), (d) ventral aspect of head and thorax of male (enlarged), and (e) male genital armature (enlarged)

¹ *Kalatitar* is the vernacular name of the Indian Black Partridge

concolorous with the head, bearing four long hairs on each side. Antennae (Text-fig. 4b) prominent, 4-jointed, I segment squat; II segment pyriform; III segment ventricose at the apex and stalked, inserted apically in segment II; IV segment cylindrical, truncate and excavated at the apex with several long hairs. Spinous process short, claw-shaped, 0.031-0.034 mm. long.

Pro-thorax large, expanded with acute wings; lateral angles with a short spine; posterior-lateral margins slightly concave each bearing three or four long hairs and a short spine; posterior margin nearly straight with eight long hairs and a short median protuberance; transverse bar distinct, bearing a short prickle on each end; lateral bars curved, very distinct. Meso-thorax rudimentary, lateral band distinct, completely fused posteriorly with meta-thorax. Meta-thorax short, broad; with slightly convex widely diverging sides, bearing about six spines; posterior lateral angle with two long hairs; posterior margin almost straight or slightly convex, bearing about sixteen long and a short hair. Legs concolorous with the thorax, marginal markings on femora and tibia narrow, yellowish; hind femora with a ventral patch of short hairs. Pro-sternal plate present, pale, quadrate, expanded basally, with two fine short hairs; coxae of first pair of legs almost touching each other. Ptero-sternum with numerous long hairs, disposed of as shown in figure 4d.

Abdomen broadly elliptical, widest at the fourth segment, length of segments nearly subequal; posterior angles of segments slightly projecting; posterior margins nearly straight, bearing about twenty to twenty-eight hairs; posterior margin of the last segment broadly rounded, bearing one long and several short hairs on each side. Ventral surface of each abdominal sternite bearing two rows of short and weak hairs, and a patch of numerous short hairs on each side of IV-VI sternites, merging more or less with general chaetotaxy. Pleural plates distinct with several short, irregularly scattered setae. Last segment with a distinct genital plate bearing about eight short hairs on either side.

Genitalia (Text-fig. 4e) characteristic, basal plate short; parameres thinly chitinized and pointed towards their free ends; distal plate flat with well chitinized slender rods on each side.

Female: not available.

Measurements (mm) of Uchida kalatitar sp. nov.

3 Males.	(Holotype)		(Paratype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.299	..	1.193-1.269	....
Head ..	0.308	0.485	0.240-0.288	0.451-0.461
Pro-thorax ..	0.173	0.384	0.154-0.163	0.356
Ptero-thorax ..	0.145	0.432	0.145	0.384
Abdomen	0.673	0.548	0.654-0.673	0.461-0.481
Head-index	1.575		1.579-1.921	

Holotype: A male mounted on slide No. MA. 056H from Lyallpur, 12.xi.1933, ex the Indian Black Partridge, *Francolinus f. asiæ* Bonap. *Paratypes*: two males on slide No. MA. 056P (same data as above).

This form resembles *Uchida perdicis* (Denny) from *Perdix cinerea*. It is not possible to sort out differences from Denny's brief description. However, it is apparent from the figure, that the new species is distinguished from it, amongst other characters, by the absence of the fuscous spot on each side of the clypeus and by considerably small size.

6. *Eomenacanthus stramineus* (Nitzsch).1874. *Menopon stramineum*, Nitzsch, in *Giebel's Ins. Epiz.*, p. 291.

This familiar species of louse has been recorded from practically all parts of the world *ex* the Domestic Fowl, *Gallus g. domesticus* Linn. Nitzsch (1874), Piaget (1880) and Sugimoto (1920) also recorded it from various other birds, viz., *Meleagris gallopavo*, *Euplocamus caviere*, *Pavo m. muticus* Linn., *Phasianus colchicus*, etc. It is a common parasite of domestic fowls in India, and the specimens referred to here were taken off the Domestic Fowl from Lyallpur, Lahore, Attari, Amritsar, Dhariwal, Pathankot and Bijnor (U.P.).

Measurements (mm.) of Eomenacanthus stramineum (Nitzsch).

	15 females.		20 males.	
	Length.	Breadth.	Length.	Breadth.
Total	2.30-2.94	.....	2.46-2.90	.....
Head	0.30-0.36	0.60-0.68	0.30-0.40	0.60-0.68
Pro-thorax	0.28-0.30	0.46-0.56	0.26-0.32	0.48-0.52
Ptero-thorax	0.20-0.24	0.50-0.60	0.20-0.30	0.50-0.56
Abdomen	1.50-2.00	0.76-0.90	1.60-1.98	0.76-0.90
Head-index	1.833-2.006		1.7-2.0	

Piaget (1880) gave the measurements of female and male as 2.75 mm. \times 1.00 mm. and 2.95 mm. \times 0.90 mm. respectively, while head-index (head length: breadth) calculated = 1.55 and 1.625.

7. *Menacanthus gonophoeus* (Nitzsch).

This species was first described from specimens obtained *ex* the Raven, *Corvus corax* Linn.; in Europe and since then it has been recorded from the Pied Crow, *Corvus albus* Mull.; the Black Crow, *Heterocorax capensis* Licht.; the Rook, *Corvus frugilegus* Linn.; etc., from different parts of the world.

The present material was collected from the Punjab Raven, *Corvus corax laurencei* Hume; and the Eastern Rook, *Corvus frugilegus tchusii* Hartert; from various parts in the Punjab.

8. *Menacanthus masudi* Qadri.1935. *Menacanthus masudi*, Qadri, *Z. Parasit.*, VIII, p. 227, fig. 2.

Qadri (1935) described it from specimens taken off the Common Indian House Crow, *Corvus s. splendens* Vieill.; in Aligarh. The specimens referred to here were collected from the type-host in Lyallpur, 19.ii.1936.

Measurements (mm.): Length \times Breadth.

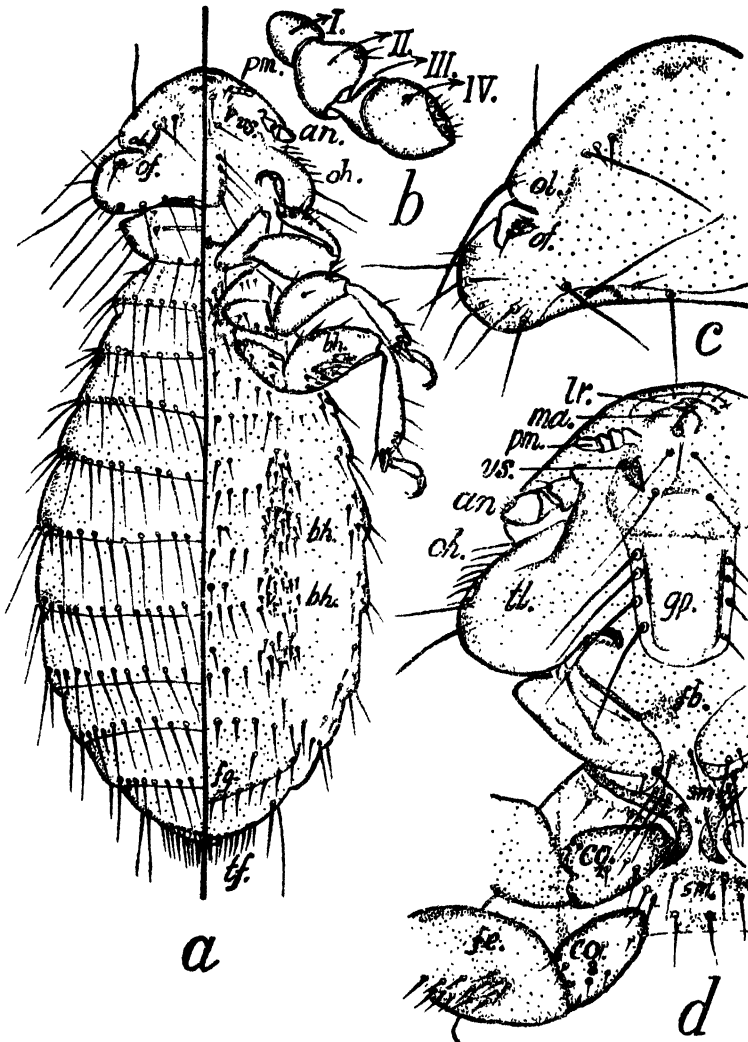
Female: Total 2.30 \times 0.96, head 0.30 \times 0.70, pro-thorax 0.22 \times 0.56, ptero-thorax 0.18 \times 0.60, abdomen 1.06 \times 0.96, head-index 2.33.

Qadri (1935) gave the measurements of female and male as 2.5 mm. \times 0.91 mm. and 1.945 mm. \times 0.74 mm., while head-index calculated = 2.109 and 1.937 respectively.

9. *Menacanthus guldum*¹ sp. nov.

Female (Text-fig. 5a): Ground colour of the body pale, with yellowish-brown markings on head and thorax, and faint abdominal bands.

Head short, broad, front parabolic; two long hairs on the lateral margin, two short hairs and a long hair on the dorsal surface of head; ocular slit narrow and deep. Eyes large, flat, with a slight latero-median concavity; ocular fleck black, kidney-shaped, with a short posterior hair. Temples expanded, rounded; bearing a fringe of short, stiff hairs on the anterior margin, just below the eyes; each lobe posteriorly furnished with two short, three long and several fine hairs. Occipital



TEXT-FIG. 5. *Menacanthus guldum*, sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) dorsal aspect of a portion of head showing ocular slit and eye (enlarged), and (d) ventral aspect of head and thorax (enlarged).

¹ *Guldum* is the vernacular name for the Punjab Red-Vented Bulbul.

margin slightly concave, edged with very narrow, pale-brown marginal band and dark-brown blotch, bearing six hairs. On the ventral aspect of the head, mandibles situated fairly close to the anterior margin; clypeal region and labrum reduced; oesophageal sclerite vestigial, oesophageal glands wanting; chitinous framework for articulation of mandibles well developed; antennal fossae not deep, dorsal flap entire, ventral flap partial, posterior inner border chitinized, pale-brown. Antennae (Text-fig. 5b) 4-jointed, scape simple and short, segment II pear-shaped with bluntly produced outer margin, segment III calyx-like, with obliquely straight basal stalk driven subapically into segment II, segment IV cone-shaped with several sensory fine hairs confined to outer latero-apical margin. Quadrate ventral sclerite weak with four long lateral hairs. Spinous processes hyaline, blunt, peg-like, small, about 0.035 mm. long.

Pro-thorax short, protruded, lateral angles obtusely expanded, each with a short spine; posterior lateral margin almost straight, each with a spine and two long hairs; posterior margin straight, furnished with six long hairs. Transverse bar distinct; longitudinal bar yellowish-brown, well developed towards the scapular margin, a short hair at the meeting place of transverse and longitudinal bars. Mesothorax reduced, lateral band distinct, yellowish-brown. Meta-thorax short, almost of the size of pro-thorax; lateral margins straight, divergent posteriorly, each with a spine on the anterior margin, each posterior angle with two long hairs and a spine, posterior margin almost straight with two spines and twelve long hairs. Legs concolorous with the body, hinder femora with thin patches of short hairs. Pro-sternum present, with a central quadrate plate and lateral chitinized arm, running along the procoxal plates; meso- and meta-sternum well separated with several long hairs, meso- and meta-legs with well chitinized pericoxal plates.

Abdomen broadly elliptical, widest at IV-V segments, length of segments sub-equal, posterior angles produced, each bearing two long hairs; posterior margin almost straight each furnished with sixteen to twenty-four hairs of which outer 2-3 are spinous; posterior margin of the last segment broadly rounded with two long hairs on each side and a fringe of fine hairs between them; tergal plates faintly coloured, distinct, entire. Ventrum with two transverse rows of hairs, anterior one being small and the posterior one entire; group of several hairs on each side of IV-VI sternal plates, merging more or less with transverse rows of hairs. Pleural plates with several irregularly scattered spinous hairs. Genital plate distinct, lying on VIII-IX sternites, posterior margin with several short hairs.

Male: not available.

Measurements (mm.): Length \times Breadth.

Holotype (Female): Total 1.639 \times 0.713, head 0.277 \times 0.509, pro-thorax 0.139 \times 0.370, pterothorax 0.140 \times 0.389, abdomen, 1.083 \times 0.713, head-index 1.845.

Holotype: A female from Lyallpur, 14.i.1928, on slide No. MA. 018, ex the Punjab Red-Vented Bulbul, *Molpastes cafer intermedius* (Jerdon).

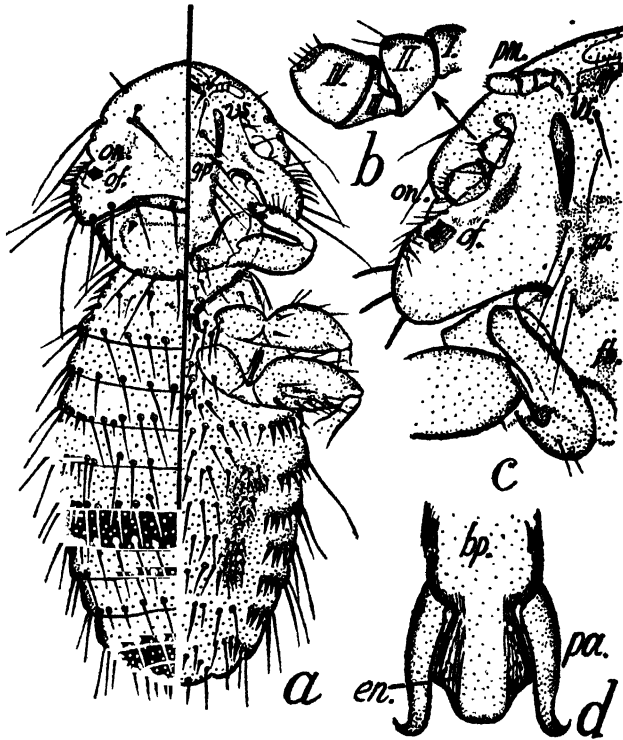
This species is close to *M. microsceli* Uchida from the Brown-eared Bulbul, *Microscelis amaurotis*; but differs from it, amongst other characters, in the general chaetotaxy and shape of the last abdominal sclerite.

10. *Menacanthus safedgal*¹ sp. nov.

Male (Text-fig. 6a): very small, wide bodied form; ground colour brownish-yellow with dark-brown markings on head.

¹ *Safedgal* is the vernacular name for the White-cheeked Bulbul.

Head comparatively large, pre-antennal region almost twice as long as the post-antennal region, front broadly parabolic; one short and two long hairs on the



TEXT-FIG. 6. *Menacanthus safedgal*, sp. nov.: (a) dorsal and ventral aspects of male, (b) antenna of male (enlarged), (c) ventral aspect of a portion of head and pro-thorax of male (enlarged), (d) male genital armature (enlarged).

lateral margin; two short and a long hair on each side of the dorsum of head; ocular slit narrow, indistinct. Eyes large, double cornea, with nearly quadrate fleck, bare. Temples slightly expanded; margin flatly rounded, each bearing three long and several subequal hairs, fringe of stiff hairs along the margin, just below the eyes. Occipital margin concave, edged with dark-brown band on the lateral margin, bearing eight long hairs. On the ventrum, mandibles situated a short distance behind the anterior margin; labrum distinct with numerous short hairs irregularly scattered on the posterior margin, oesophageal sclerite and glands wanting, gular plate faintly chitinated, quadrate with posterior concavity, bearing four long hairs on each side. Antennal cavity completely covered above, lower flap almost one-third of upper flap in breadth; inner chitin of the fossa dark-brown. Antennae (Text-fig. 6b) 4-segmented, scape quadrate, placed over it is the irregularly pyriform segment II, segment III calyciform, with shallow cup and short peduncle inserted apically on one side of segment II; segment IV irregularly cone-shaped with a grooved subapical margin. Spinous process (Text-fig. 6c) large, reaching as far as the imaginary line joining the eyes, 0.073–0.078 mm. long.

Pro-thorax large, protruded, lateral angles rectangular, rounded, each with a spine; posterior lateral margin almost straight, with two long hairs and a spine in between; posterior margin slightly convex, with four long hairs on each side of

median conical protuberance; transverse bar distinct, with short median longitudinal bar running posteriorly and a spine on each lateral end; lateral bars distinct, reaching as far as scapular region, dark-brown. Meso-thorax fused with the posterior segment; lateral bar distinct, reaching as far as pro-thorax, running inwards for some distance and then backwards and inwards; bearing a spine and 2-3 fine dorsal hairs on each half. Meta-thorax short, broader than pro-thorax, lateral margins straight, each with four spines; lateral bar distinct; posterior lateral angle with a spine and a long hair; posterior margin slightly convex, bearing two short spines and eight long hairs. Legs concolorous with the body, with brownish marginal markings and short marginal hairs; hind femora with brief ventral patch of stiff, short hairs. Pro-sternum distinct; central piece lightly pigmented, squarish blotch; lateral bars strongly built, running along the coxal plates as far as the scapular margin. Meso-sternum confined between the two meso-coxal bars, which almost touch each other in the middle, about four hairs on each posterior margin and several short ones scattered above. Meta-sternum four-sided, two hairs on each frontal margin and two such hairs on each posterior margin.

Abdomen elliptical, widest at the III segment, length of segments almost equal, posterior angles produced, each bearing one short and a long hair; posterior margins of segments I-III slightly convex, of segments IV-VI almost straight, and of VII-VIII concave; each segment bearing a transverse row of long hairs of which lateral 2-3 becoming spinous; segment IX with two hairs on the posterior projecting angle, last segment short, flatly rounded with about 8-10 marginal hairs. Abdominal sternites, each bearing a row of short weak hairs and several spinous hairs on each side; sternites III-VII with patch of fine hairs on each end, merging more or less with transverse row of hairs. Pleural plates well developed, with several spinous hairs on the posterior margins. Genitalia (Text-fig. 6d) pale, short, parameres faintly chitinized with strongly, outwardly recurved ends; endomeral plate well developed with well chitinized lateral ends.

Female: not available.

Measurements (mm.) Length \times Breadth.

Holotype (Male): Total 1.128×0.455 , head 0.250×0.431 , pro-thorax 0.130×0.325 , ptero-thorax 0.122×0.374 , abdomen 0.626×0.455 , head-index 1.728.

Holotype: One male from Kulu, 2.x.1939, on slide No. MA. 019, ex the White-cheeked Bulbul, *Molpastes l. leucogenys* (Gray).

The present species is distinguished from other species of the genus, by the shape of the head, body size, general chaetotaxy, by the male genitalia, and other details.

11. *Menacanthus dudiyalatora*¹ sp. nov.

Female (Text-fig. 7a): broadly elliptical, brownish-yellow, with yellowish-brown markings on head and thorax.

Head broad, slightly little less than twice as broad as long; front rounded, two short hairs on each side of meson; lateral margins with a small and three long hairs; lateral angles rounded; two short and one long hair on dorsum; ocular slit distinct. Eyes large, concave in the middle, ocular fleck oblong with a minute spine; temples swollen, slightly expanded, rounded with five long and several short hairs; a comb of stiff hairs on the ventrally produced margin, occipital margin slightly concave, edged with narrow, brown chitinous band, bearing three long hairs on each half. On the ventral side of head, mandibles situated a short distance

¹ *Dudiya-latora* is the vernacular name for the Indian Great Grey Shrike.

behind the frontal margin, labrum almost touching the forehead; frontal chitin yellowish-brown, continues backwards and downwards to the mandibular articulation. Antennal fossae deep; with well chitinized inner margin, dark-brown. Antennae (Text-fig. 7b and 7k) 4-jointed, projecting; scape simple and short; segment II irregularly pear-shaped, with subapical margin produced to one side; segment III ventricose at the apex and stalked, inserted apically in the middle of segment II; segment IV ovate, with numerous sensory apical hairs. Gular plate quadrate, faintly chitinized, each side with four long hairs of which the posterior one is longest. Spinous pegs, short and delicate, 0.033 mm. long.



TEXT-FIG. 7. *Menacanthus dudiyalatora* sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) dorsal and ventral aspects of male, (d) antenna of male (enlarged), (e) dorsal aspect of a portion of head showing the ocular slit and eye (enlarged), (f) ventral aspect of head (enlarged), (g) a patch of several irregularly scattered short hairs on the sides of III abdominal sclerite (enlarged), (h) genital armature of male (enlarged), (i) posterior femora, showing group of ventral hairs (enlarged), (j) terminal segment of maxillary palp (enlarged), and (k) terminal segment of antenna (enlarged).

Pro-thorax large, lateral angles each with a spine and a long hair; lateral margin slightly convex, each bearing a spine and a long hair, posterior margin nearly straight, bearing three long hairs on each half; transverse band distinct, a short spine on lateral ends; lateral longitudinal bars well chitinized, dark-brown. Meso-thorax reduced, distinct; meta-thorax short, broader than pro-thorax, lateral margin almost straight, diverging posteriorly; posterior angle with two spines;

posterior margin almost straight, bearing five long hairs and a spine on each half, legs somewhat paler than the body with distinct marginal markings and roughly scattered short hairs, posterior femora (Text-fig. 7i) with a group of hairs on the ventral surface. Pro-sternum reduced, the coxae of the foot-jaws almost touching each other; meso- and meta-sternum and peri-coxal plates well developed, bearing several long hairs as shown in figure.

Abdomen broadly elliptical, widest at IV-V segment, posterior angles of the segments projecting; each with two long hairs; posterior margins of the segments almost straight, each bearing a transverse row of 14-20 hairs of which lateral 2-3 becoming very small; posterior margin of the last segment truncate, bearing one long and a short hair on each side of a fringe of fine hairs and six short hairs dorsal to the fringe. On the ventral surface, each abdominal sternite with a transverse row of hairs and a smaller row of irregularly arranged short hairs; several irregularly scattered short hairs on each side also present, merging more or less with general chaetotaxy.

Male (Text-fig. 7c): similar to female, but size considerably small, abdomen smaller and narrower; ventrum with one row of hairs and a group of short hairs on each side of it. (Genitalia (Text-fig. 7h) pale, well chitinized, basal plate long, distally flat, articulating with a flatly rounded lamina; on each side of which is a slender outwardly recurved paramere; preputial sac beset with curved spines.

Measurements (mm.) of Menacanthus dudiyalatora sp. nov.

	Female (Holotype).		2 males.	
	Length.	Breadth.	Length.	Breadth.
Total ..	1.826	..	1.513-1.591	?
Head ..	0.281	0.534	0.242-0.292	0.505-0.553
Pro-thorax ..	0.165	0.398	0.155-0.194	0.359-0.378
Ptero-thorax ..	0.147	0.534	0.126-0.136	0.408-0.485
Abdomen ..	1.233	0.835	0.971-0.990	0.650-0.679
Head-index ..	1.9		1.906-2.086	

Holotype: A female from Lyallpur, 19.xi.1930, on slide No. MA. 02311. *Allotype*: A male from Lyallpur, 4.iv.1928, on slide No. MA. 023A ex the Indian Great Grey Shrike, *Lanius excubitor lahtora* (Sykes). *Paratype*: A male from Lyallpur, 27.ii.1936 (same data as above).

This species resembles *Menopon coarctatum* (Scopoli) from the Red-backed Shrike, *Lanius collurio* but is distinguished from it by the differences in size, the general chaetotaxy, and by the male genitalia.

12. *Menacanthus gulabimaina*¹ sp. nov.

Female (Text-fig. 8a): body large and oval, pale-brown with brownish markings on head and thorax.

Head comparatively short; front broadly parabolic, two minute hairs on each side of meson; lateral margins slightly concave, each bearing one small and a long hair, two long hairs in the lateral angles; one long and two short setae on the dorsal surface of the head; ocular emargination shallow, continued into a slit; eyes large, emarginated, double cornea; ocular fleck irregularly rectangular, black, a short seta in the notch and another situated posteriorly; temples moderately

¹ *Gulabimaina* is the vernacular name for the Rose-coloured Starling.

expanded, rounded laterally, bearing about seven stiff, short, posteriorly bent setae, then five long and six short setae; occipital margin slightly concave, edged



TEXT-FIG. 8. *Menacanthus gulabimaina*, sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) maxillary palp of female (enlarged), (d) dorsal aspect of a portion of head showing ocular notch, slit and eye (enlarged), and (e) ventral aspect of a portion of head and thorax (enlarged).

with dark brown chitin, bearing three long hairs on each side. On the ventral aspect of the head; mandibles situated a short distance behind the anterior margin; labrum narrow with numerous minute and two short hairs; oesophageal sclerite and glands indistinct; plate on the gular region well developed, extending beyond the occipital margin, quadrate, with deeply concave posterior margin, bearing

four long hairs on each side. Inner border of antennal fossae highly chitinized, dark-brown; antennae (Text-fig. 8b) projecting, 4-jointed, scape transverse, small and squat; II joint pear-shaped, with minutely produced apical margin, and slightly bulging to one side; III joint bell-shaped, pedunculate basally and regularly diverging towards the apex, basal stalk tucked in submedially on the apex of segment II; segment IV elongate, irregularly cylindrical, with sub-apical groove furnished with minute hairs, visible hairs disposed of as in figure. Ventral spinous spatula (Text-fig. 8e) running backwards as far as or even beyond gular plate, straight, 0.112–0.130 mm. long.

Pro-thorax large, protruding, lateral angles obtuse, each with a spine; posterior lateral margin slightly convex, each with two long hairs and a spine; posterior margin straight, with four long hairs on each side of a short median keel; transverse bar distinct with a minute spine on the lateral tip, curved long bars at its end, well chitinized, dark-brown. Meso-thorax narrow; lateral bands narrow, well chitinized, dark-brown, bare; posterior margin with two minute spines on each side. Meta-thorax short and broad, lateral margins slightly convex, bearing three minute spines, diverging posteriorly; each posterior angle bearing a spine and two long hairs; posterior margin nearly straight with one spine and six long hairs on each side. Legs slightly paler than the thorax; with very narrow, brownish yellow marginal markings and roughly scattered short hairs; hind femora with several stiff hairs but no distinct patch.

Abdomen elliptical, widest at V segment, posterior angles of the segments projecting, each with a long hair and two short spines; posterior margins of segments I–V straight, and those of segments VI–VIII concave, each bearing a transverse row of long hairs, of which lateral three or four becoming spinous; posterior margin of the last segment broadly rounded, with one exceptionally long hair and a long hair on each side of several short hairs. A fringe of fine hairs on hyaline margin also present. Transverse bands brownish-yellow, entire; lateral bands narrow, clear brown. Ventral surface of each abdominal segment with two transverse, rows of hairs, several outer ones of the posterior row smaller, out of these 2–3 spinous; sternite III–VII, each with a patch of roughly arranged hairs. Pleural plates well developed, each with several heavy spines. Genital plate well developed, lying as far as the middle of segment IX, furnished with posterior row of 19–20 short hairs.

Male: similar to female, but size considerably small. Genital armature calls for no description.

Measurements (mm.) of Menacanthus gulabumaina sp. nov.

	Female (Holotype).		Female (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total	2.125	..	2.047	..	1.491	..
Head	0.298	0.615	0.327	0.577	0.259	0.509
Pro-thorax ..	0.201	0.481	0.211	0.461	0.173	0.404
Ptero-thorax ..	0.222	0.625	0.182	0.548	0.154	0.481
Abdomen	1.404	0.961	1.327	0.798	0.905	0.596
Head-index ..	2.068		2.764		1.965	

Holotype: one female, on slide No. MA. 026H; *Allotype*: one male, on slide No. MA. 026A; *Paratype*: one female; all from Lyallpur, 2.iii.1936, *ex* the Rosy Starling, *Pastor roseus* (Linn.).

This species resembles *Menacanthus tristis* Qadri but differs from it in the following characters: plate-like coxae of the foot-jaws touch each other in the middle; antennae short, not projecting; spinous process longer.

Piaget (1880) recorded *Myrsidea breviventris* from this host.

13. *Menacanthus himalayicus* sp. nov.

Female (Text-fig. 9a): body broadly elliptical, pale-brown, with brown and dark-brown markings on head and thorax and brownish bands on abdomen.

Head short and broad; front broadly rounded, a minute angulation on meson bare; lateral margin with two short and two long hairs; one long and two short hairs, on the dorsal surface; lateral margin continuous with the eyes, ocular slit distinct; eyes well developed, cornea flat, medially emarginated; ocular fleck irregularly squarish, bearing a short seta behind; temples narrow and produced, each lobe



TEXT-FIG. 9. *Menacanthus himalayicus*, sp. nov.: (a) dorsal and ventral aspects of female, (b) maxillary palp of female enlarged, (c) antenna of female (enlarged), (d) dorsal aspect of a portion of head showing ocular slit and eye (enlarged), (e) ventral aspect of a portion of head and thorax (enlarged), and (f) male genital armature (enlarged).

with five very long and several short hairs, a comb of stiff hairs on the margin, lying below the eyes; occipital margin concave, edged with narrow, brown chitinous bands, bearing four hairs on each half. On the ventral side of the head, mandibles situated a short distance behind the frontal margin; labrum narrow with anteriorly pointed clypeal suture; oesophageal sclerite and glands reduced; gular plate quadrate, extending beyond the occipital margin; posterior margin deeply concave, bearing four long hairs on each side. Inner border of antennal fossae highly chitinized, dark brown; antennae (Text-fig. 9c) not projecting, 4-jointed; scape squat; II joint pear-shaped, slightly produced apically to one side; III joint calyciform, IV joint cone-shaped with truncate sub-apical margin. Ventral spinous process running backwards as far as beyond gular plate, straight (Text-fig. 9e), 0.121 mm. long.

Pro-thorax large, protruded; lateral angles nearly at right angles, each with one short spine; posterior lateral margin almost straight, each with two long hairs and a spine in between; posterior margin straight, with four long hairs on each side of a central ridge, outermost of which is at a distance and longest, transverse band and lateral bars distinct, a small spine on band's end. Meso-thorax reduced, lateral bands dark-brown; meta-thorax trapezoidal, lateral margins straight, diverging posteriorly, each with three spines; posterior angle with two long hairs and a spine; posterior margin straight furnished with one spine and five long hairs on each half; legs paler than the body, with brownish margins and roughly scattered spinous hairs; hind femora with several ventral, stiff hairs. Sternal plates (Text-fig. 9e) and pericoxal bars well developed.

Abdomen elliptical, widest at the IV segment; length of segments subequal; posterior angles projecting, each bearing two long hairs and several spines; posterior margin with a transverse row of several hairs, of which outer 3-4 becoming spinous; posterior margin of the last segment truncate, bearing two long and four short hairs on each half, hyaline flap bearing fringe of fine hairs below; transverse bands yellowish-brown, entire, present across each segment; lateral bands narrow, brown. Ventral surface of each abdominal segment bearing two rows of short and weak hairs, the outer ones of the row becoming spinous. Pleural plates well developed, each with spinous posterior hairs. Genital plate across segment IX with posterior row of several fine setae.

Male: similar to female, but smaller. Genital armature (Text-fig. 9f) distinct; parameres pale, transparent with outwardly curved tips; endomeral plate, oblong with well chitinized outer rod-like structures.

Measurements (mm.) of Menacanthus himalayicus sp. nov.

	Female (Holotype).		5 Females (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.682	..	1.672-1.710	.....	1.125	..
Head ..	0.259	0.548	0.259-0.279	0.548-0.558	0.240	0.432
Pro-thorax ..	0.192	0.452	0.192	0.432-0.442	0.144	0.356
Ptero-thorax ..	0.154	0.548	0.182-0.192	0.529-0.548	0.107	0.384
Abdomen ..	1.077	0.721	1.019-1.067	0.673-0.731	0.634	0.452
Head-index ..	2.116		1.964-2.154		1.8	

Holotype: A female from Lyallpur, 10.ii.1928, on slide No. MA. 027H. *Allotype*: A male from Lyallpur, 28.iii.1929, on slide No. MA. 027A, ex the Himalayan Starling, *Sturnus vulgaris humii* Brooks. *Paratypes*: A female, 6.xi.1933, on slide and several males and females preserved in alcohol (same data as above).

This species closely resembles *Menacanthus gulabimaina* sp. nov. (*vide supra*), but differs in the shape of the head and ventral chaetotaxy.

14. *Menacanthus spiniferum* (Piaget).

1885, *Menopon spiniferum*, Piaget, *Les Pediculines* (Suppl.), p. 99, pl. 10, fig. 9.

This species has frequently been recorded from the Indian Minor, *Acridotheres t. tristis* (Linn.). The specimens referred to below were collected from the Common Indian Myna shot in Lyallpur, 16.vi.1933.

Measurements (mm.): Length × Breadth.

5 Females: Total 1.88–2.30 × 0.68, head 0.36 × 0.52, thorax 0.41 × 0.52, abdomen 1.20–1.51 × 0.68, head-index 2.0.

Piaget (1885) gave the measurements of female as 2.2–2.3 mm.–0.75 mm., while the head-index calculated = 1.714.

15. *Menacanthus quadrifasciatum* (Piaget).

1880, *Menopon quadrifasciatum*, Piaget, *Les Pediculines*, p. 440, pl. 35, fig. 6.

This species was first described from Domestic Sparrow, *Passer domesticus* Linn. Uchida (1926) recorded it from the Russet Sparrow, *Passer r. rutilans*. The specimens referred to below were collected from the Indian House Sparrow, *Passer domesticus indicus* Jard. & Selby.; shot in Lyallpur, 3.x.1930.

Measurements (mm.): Length × Breadth.

Female: Total 1.26 × 0.53, head 0.26 × 0.46, thorax 0.28 × 0.39, abdomen 0.72 × 0.52, head-index 1.769.

Piaget (1880) and Uchida (1926) gave the measurements of female as 1.3 mm. × 0.51 mm. and 1.5–1.55 mm. × 0.63–0.65 mm. respectively, while head-index calculated = 1.384 and 2.0 respectively.

16. *Menacanthus* sp.

Several immature specimens were obtained from the Indian Yellow-throated Sparrow, *Gymnoris x. xanthocollis* (Burt.); shot in Lyallpur, 4.v.1933.

Sub-family: COLPOCEPHALINAE

GALLIFERRISIA gen. nov.

The following is the preliminary description of a new genus and species of Mallophaga taken from the Common Indian Peacock, *Pavo cristatus* Linn.

The characters of *Colpocephalum* Nitzsch, to which it resembles in form and superficial appearance; include mainly 2–3 fringes of stout setae curving upwards on the posterior lateral margin of the VIII abdominal segment, combs of hind femora and III abdominal sternite as well as genitalia. The genus discussed below is similar to it as far as the presence of fringes of recurved setae on the posterior lateral margin of the VIII abdominal segment is concerned but differs considerably in many features, viz. shape of head, thoraces, combs of hind femora and abdominal sternite. There are certain other unusual anatomical structures and further studies are contemplated. The following table of comparison includes additional characters, none of these enables a sharp separation to be made but in combination they are effective.

Table showing schematical comparison of *Colpocephalum* and *Galliferrisia*.

<i>Colpocephalum</i> Nitzsch.	<i>Galliferrisia</i> gen. nov.
1. Head (seen from above) with a distinct squarish ocular notch.	1. Head (seen from above) with a deep, acutely notched, peculiar ocular emargination.
2. Head less firmly fastened to the thorax.	2. Head more firmly fastened to the thorax, overlapping pro-thorax.
3. Antenna 4-segmented with swollen, obliquely pear-shaped II joint.	3. Antenna 4-segmented, II joint pear-shaped.
4. Eyes lateral, double cornea.	4. Eyes greatly reduced, slightly ventral or absent.
5. Pro-thorax short and protruded lateral angles nearly at right angles.	5. Pro-thorax with acute wings, anterior portion deeply inserted under occipital margin, postero-lateral margin strongly confluent.
6. Meso- and meta-thorax separated with an obliterated suture.	6. Meso- and meta-thorax distinctly separated laterally with a notch.
7. Venter of the posterior femora with 2-3 combs.	7. Venter of posterior femora with 4-5 combs of hairs.
8. III abdominal sternite with a pair of diagonally set combs of spines.	8. III abdominal sternite with 4-5 pairs of diagonally set combs of spines.
9. Male genitalia with complex chitinous structure near the apex of the basal plate.	9. Male genitalia with complex chitinous structure as in <i>Colpocephalum</i> , but modified in essential characters.
10. Female genital plate simple.	10. Female genital plate rugose.

Description of the genus.—Head about one and half times wider than long; forehead broadly rounded; lateral margins, in front of the eyes, with a notch; eyes wanting or vestigial, ventral, situated far away from the margin; ocular fleck situated immediately near the occipital band. Antennae 4-jointed as shown in text-figure, extending outwards beyond the border of the head. Mandibles situated a short distance behind the anterior margin. Oesophageal sclerite well developed. Gular plate well marked, but feebly sclerotic. Pro-thorax well formed, wings acute. Ptero-thorax with distinct marginal suture, meso-notum short, intercoxal plates and sternum as shown in text-figure. Legs normal, posterior femora with four-five combs of spines on the ventrum. Abdomen elongate, tapering posteriorly; tergal and sternal plates well formed. Chaetotaxy as shown in text-figure; VIII abdominal pleurite in the female with about ten stout hairs, curving upwards around the sides of the segment; III sternite with four-five combs of spines. Sexes dimorphic. Male genitalia more or less as in *Colpocephalum* Nitzsch.

This genus is apparently confined to Pea-fowls (Phasianidae).

Type of the genus: *Galliferrisia tausi* sp. nov. (vide *infra*) ex the Common Pea-fowl, *Pavo cristatus* Linn. There is some probability that *Colpocephalum echinatum* Ewing, and *Colpocephalum thoracium* Kellogg and Paine described from *Pavo muticus*, belonging to this genus, but it is impossible to draw a more exact conclusion from the descriptions available to me.

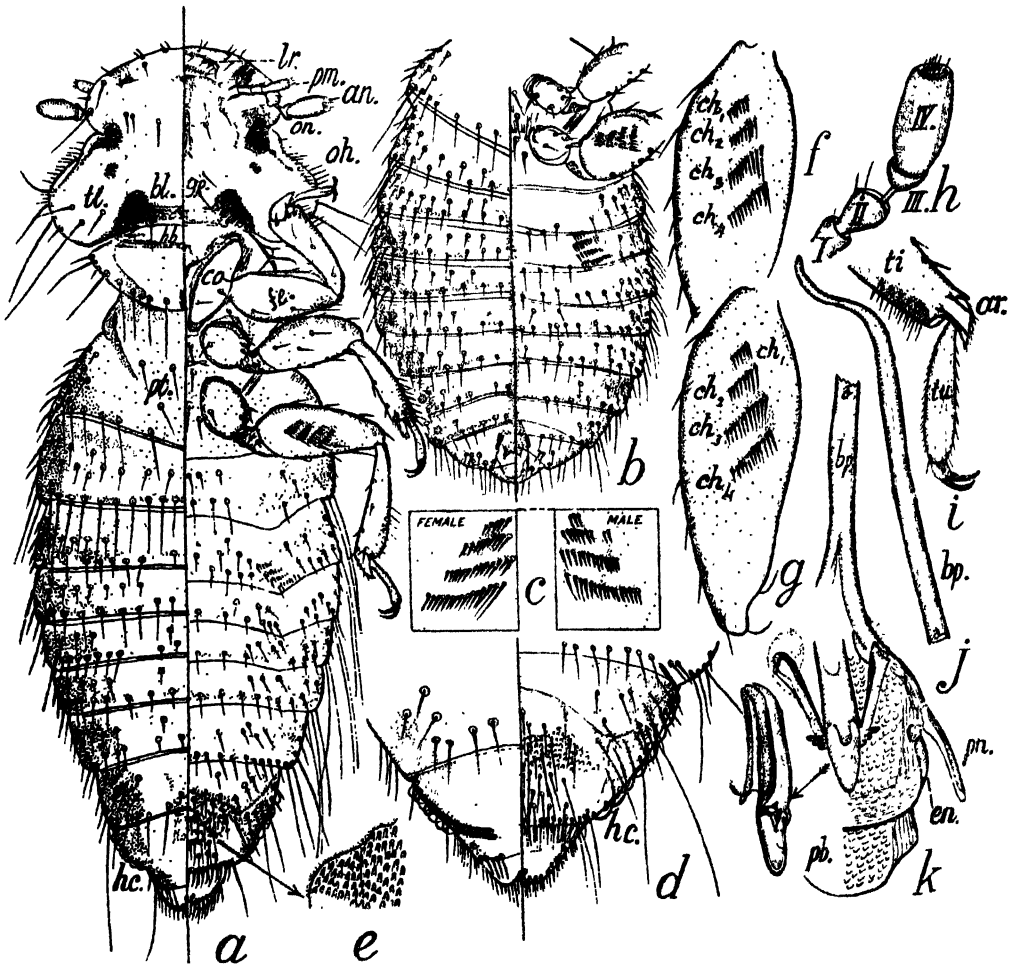
17. *Galliferrisia tausi*¹ sp. nov.

Female (Text-fig. 10a): pale brownish-yellow, with dark-brown markings on head and distinct abdominal bands.

Head broader than long, front broadly rounded with dorsal and ventral hairs arranged as in text-figure, ocular notch moderately deep, acutely angled, with

¹ 'Taus' is the Persian name of the Common Indian Pea-fowl.

dark-brown blotch immediately behind. Eyes far behind the margin, hence not visible; ocular fleck situated about the middle line of temples; temples broad, rounded, moderately spread, bearing dorsal and ventral hairs; a row of small, stiff hairs below the eyes; occipital margin concave with deep-brown marginal band and pitchy-brown blotch, continued to the occipital band, gular plate quadrate, well developed, feebly sclerotic; oesophageal sclerite and glands well formed; palpi projecting; antennae (Text-fig. 10*h*) 4-jointed, projecting; I joint of usual shape, II joint swollen submedially, obliquely reduced apically; III joint calyciform, cup shallow, oblique, stalk inserted apically on segment II; IV joint cylindrical, well developed; apical depression well marked, studded with sensory hairs.



TEXT-FIG. 10. *Galliferrisia tarsi*, sp. nov.: (a) dorsal and ventral aspects of female, (b) dorsal and ventral aspects of thorax and abdomen of male, (c) combs of hairs on the III abdominal sternite (enlarged), (d) dorsal and ventral aspects of the tip of the abdomen of female (enlarged), (e) rough genital blotch (enlarged), (f-g) ventral aspect of posterior femora showing combs of hairs (enlarged: f-male, g-female), (h) antenna of female (enlarged), (i) posterior tibio-tarsus joint (enlarged), and (j, k) male genital armature (enlarged).

Pro-thorax large, expanded with produced lateral angles, well towards the frontal margin; posterior margin convex, furnished with a series of hairs as shown in text-figure; transverse bar and longitudinal bands distinct. Meso-thorax narrow, lateral notch distinct; posterior suture obliterated, bearing two short hairs. Meta-thorax trapezoidal; lateral margins strongly divergent, furnished with numerous short hairs; posterior lateral angles produced, bearing short hairs, pigmented; posterior margin flatly convex on the I abdominal segment, transverse row of hairs disposed of as in text-figure. Legs well developed concolorous with the body, with narrow marginal markings and annular bands on femora and tibia; hind femora (Text-fig. 10g) with four combs of short, stiff hairs on the ventrum, proximal row being shortest, and III-IV rows subequal. Sternal plates, intercoxal bands and bars as in text-figure.

Abdomen elongate, widening posteriorly to the III segment, broadest in II-III segments, then tapering gradually to posterior end; tergites well sclerotized, entire; about two transverse rows of hairs on I-VII segments; segment VIII with ten stout hairs, curving upwards around the sides of the segment; last segment short, posterior margin notched in the middle. On the ventral surface each segment with rows of hairs as in text-figure; sternal plate III (Text-fig. 10c) provided with four combs of setae, anterior row with 5 setae and remaining three have 9, 13 and 15 setae respectively. Genital plate well formed, studded with hairs, surface rough (Text-fig. 10e). General chaetotaxy as in figure.

Male (Text-fig. 10b): similar to female, small; with ovate abdomen; last segment flatly rounded; upwardly curved hairs on the VIII pleural plate, wanting. Male genitalia (Text-fig. 10j, k) well developed; elongate, reaching from the posterior margin of the first segment to the end of the last segment; strongly expanded at the apex; paramere rod-like, straight; endomere short, preputial sac covered over with numerous recurved hooklets; complex chitinous structure in the preputial sac also present.

Measurements (mm.) of Galliferrisia 'ausi' sp. nov.

	Female (Holotype)		5 females (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.545	..	1.546-1.771	..	1.292	..
Head ..	0.320	0.533	0.320-0.386	0.533-0.577	0.293	0.493
Pro-thorax ..	0.186	0.386	0.173-0.196	0.360-0.400	0.146	0.280
Ptero-thorax ..	0.226	0.506	0.200-0.226	0.466-0.546	0.160	0.400
Abdomen ..	0.813	0.546	0.840-0.986	0.640-0.666	0.693	0.533
Head-index ..	1.665		1.484-1.665		1.683	

Holotype: A female from Hoshiarpur, 14.viii.1928, ex the Common Pea-fowl, *Pavo cristatus* Linn.; on slide No. MA. 053H. *Allotype*: one male. *Paratypes*: two females and one male on slide No. MA. 053P (same data as above), females and males from Atari (near Lahore) ex the Common Pea-fowl, 19.v.1934.

Colpocephalum appendiculatum Nitzsch, *C. longicorne* Rudow, *C. longi caudum* Piaget and *C. spinosum* Piaget are described from various Aleoetoropodes. The species under discussion does not resemble any one of them.

This new species somewhat resembles *Colpocephalum echinatum* Ewing, but is easily distinguished from it by smaller size and general chaetotaxy. In *C. thoracicum* Kell. and Paine, the abdomen of the female is not drawn out.

18. *Colpocephalum tricinatum* Nitzsch.

1861, *Colpocephalum tricinatum*, Nitzsch, in Giebel, *Ziet. f. ges. Nat.*, XVII, p. 524.

This species has been recorded from most parts of the world *ex* various species of *Milvus* and *Elanus*. The specimens referred to here were collected from the Pariah Kite, *Milvus migrans gorinda* Sykes; from Lyallpur, 5.iv.1933.

Measurements (mm.): Length × Breadth.

8 Females: Total 1.37–1.51 × 0.52–0.55, head 0.26–0.33 × 0.47, thorax 0.23–0.29 × 0.36–0.37, abdomen 0.92–0.95 × 0.52–0.56, head-index 1.424–1.624.*

Piaget (1880) gave the measurements of female as 1.4 mm. × 0.5 mm., while females of various synonyms, viz. *C. dissimile* Piaget (1880), *C. osborni* Kellogg (1896), *C. o. costaricense* Uchida (1926) and *C. abruptofasciatum* Mjöberg (1910) measured 1.5 mm. × 0.54 mm., 1.47 mm. × 0.63 mm., 1.23–1.7 mm. × 0.58–0.60 mm. and 1.487 mm. × 0.55 mm. respectively. The head-index is calculated at 1.4, 1.5, 1.6, 1.552–1.621 and 1.461 respectively.

19. *Colpocephalum* sp.

A female specimen was collected from the Himalayan Griffon Vulture, *Gyps himalayensis* Hume; Lyallpur, 9.i.1930.

20. *Colpocephalum* sp.

Two females were collected from the Lagger Falcon, *Falco juggar* Grey; Lyallpur, 5.i.1929.

21. *Pseudocolpocephalum doriabagla*¹ sp. nov.

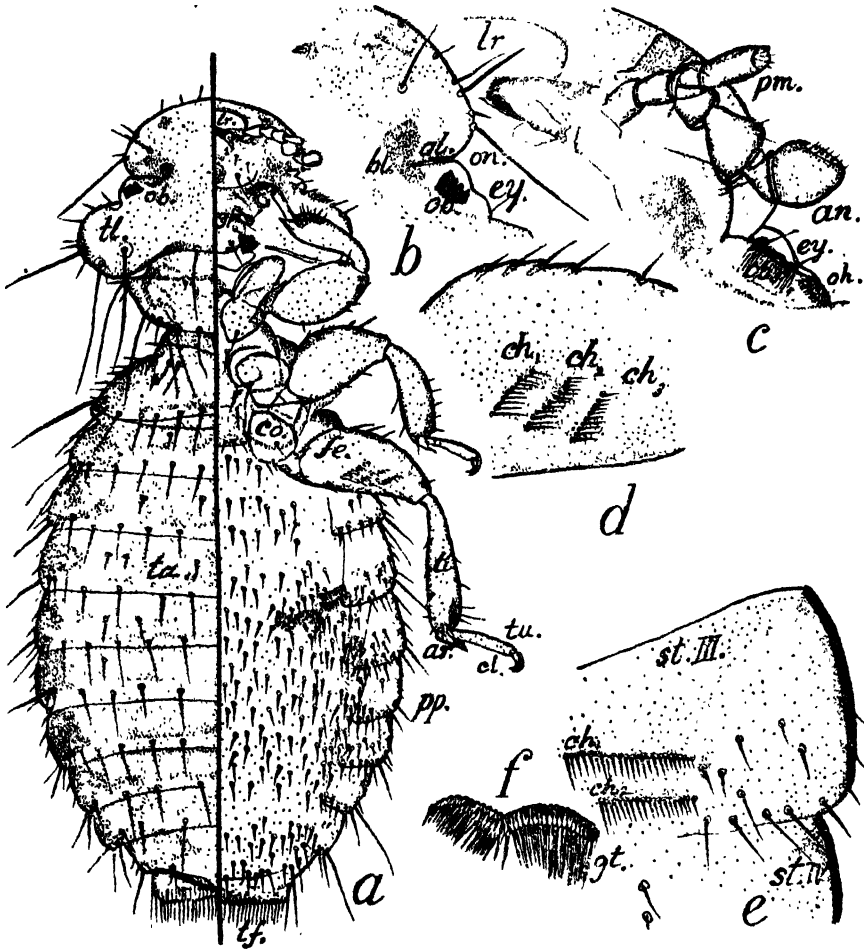
Female (Text-fig. 11a): body oval in outline, yellowish-brown, with dark brown markings on the sides of head, thorax and abdomen.

Head almost twice as broad as long; front broadly rounded with 3–4 short hairs, and a long hair at the angle in front of ocular emargination; dorsal surface of the forehead bearing a long hair on each side of the anterior end of the dark-brown ocular blotch; ocular emargination (Text-fig. 11b) shallow, acute narrow slit inwards; eyes large, prominent, emarginate; ocular fleck black, irregularly quadrate, bare; temples very much expanded, margins rounded, each bearing two long and several short hairs, a long hair on the dorsal surface of the lobe; temporal band dark-brown, occipital margin concave, edged with highly chitinized, dark-brown band, bearing two long and two minute hairs. Ventral framework for support of the mandibles well chitinized, continued forwards to the anterior clypeal margin on each side of the labrum, thence extending to the inner border of the antennary fossae, where the chitin is thick and hard; gular area yellowish-brown, weakly chitinized, bearing four hairs on each side; occipital blotch dark-brown. Antennal fossae deep, dorsal flap exceeding ventral flap slightly near the base, ventral flap with two long hairs and a comb of stiff hairs just below the eyes.

Pro-thorax more than twice as broad as long; slightly produced, lateral angles acute, each with one spine and a long hair; latero-posterior margins with an anterior spine and a posterior long hair; posterior margin slightly convex, bearing one spine and four long hairs on each side of a short, cylindrical middle ridge; transverse bar well chitinized, continued to lateral bars on each side, with a minute spine on the junction. Meso-thorax distinct, narrow; lateral chitin deep brown, bearing short spine in the middle. Meta-thorax almost as long as pro-thorax;

¹ *Doriabagla* is the vernacular name of the Cattle Egret.

lateral margins convex, diverging posteriorly, each with six spines; lateral bands well chitinized, each latero-posterior angle with a spine and a long hair; posterior



TEXT-FIG. 11. *Pseudocolpocephalum doriabagla*, sp. nov.: (a) dorsal and ventral aspects of female, (b) dorsal aspect of a portion of head showing ocular slit and eye (enlarged), (c) ventral aspect of a portion of head (enlarged), (d) ventral aspect of posterior femora showing combs of hairs (enlarged), (e) III sternite showing combs of hairs (enlarged), and (f) gastric teeth (enlarged).

margin convex with 12 long hairs. Legs paler than the body, femoral and tibial margin chitinized, hind femora (Text-fig. 11d) bearing three ventral combs of stiff hairs. Pro-sternum well formed, central plate faintly chitinized; lateral bars highly chitinized, running along the anterior margin of the plate-like coxae, which almost touch each other in the middle; meso-sternum reduced, pericoxal bars well chitinized; meta-sternum oblong with several hairs, pericoxal bars present.

Abdomen broadly elliptical; widest at the IV segment; length of the segments almost equal, lateral margins well chitinized, with several short setae, lateral bands dark-brown; posterior angles projecting, each bearing two long hairs; posterior margins of segments I-V nearly straight, of segments VI-VIII slightly concave,

each bearing a marginal row of hairs; tergites strongly chitinized, I-V with some short hairs scattered here and there, forming no regular row; segment IX longer, bearing two hairs on the lateral margin, one long hair on the latero-posterior angle; posterior margin convex with one hair; tergal plate interrupted in the middle, a fringe of fine hairs along the antero-posterior margin. Ventral surface of each abdominal sternite with transverse row of hairs, becoming numerous on the sides of several sternites and assuming the form of a patch, sternites I-VII with three rows, while VIII-IX with two rows of hairs. Sternite III with two combs of spines (Text-fig. 11e), set slightly diagonally on the posterior lateral angle; segment IX beset with a row of marginal setae; pleural plates well developed, each with several short hairs, mostly scattered on the posterior half. Gastric teeth present (Text-fig. 11f).

Male: not available.

Measurements (mm.): Length \times Breadth.

Holotype (female): Total 1.606×0.686 , head 0.284×0.549 , pro-thorax 0.166×0.362 , ptero-thorax 0.185×0.461 , abdomen 0.971×0.686 , head-index 1.933.

Holotype: A female from Lyallpur, 7.ix.1929, on slide No. MA. 063, ex the Indian Cattle Egret, *Bubulcus ibis coromandus* (Bodd.).

This species is similar to *Pseudocolpocephalum uchidi* Qadri. It is distinguished from it, amongst other characters, by (i) the shape of the head, (ii) shape of the ptero-thorax, (iii) last abdominal segment, and (iv) dorsal and ventral chaetotaxy.

22. *Cuculiphilus upak*¹ sp. nov.

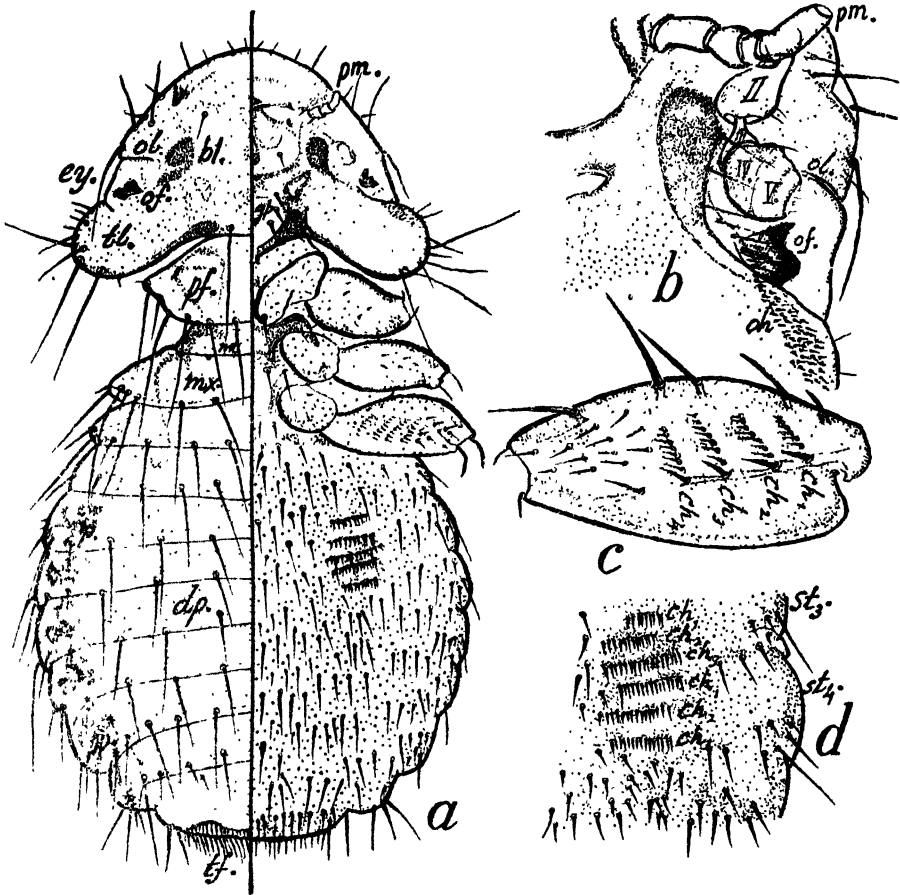
Female (Text-fig. 12a): body robust, abdomen rotundate, yellowish-brown with dark-brown markings.

Head yellowish-brown, with highly chitinized and strongly pigmented framework; front broadly parabolic, several short and long marginal hairs, one on the lateral angle being longest; one short hair on the dorsum. Ocular slit narrow, deep, backed by a dark-brown blotch. Eyes prominent, almost straight; ocular fleck black, roughly kidney-shaped. Temples broad, expanded, rounded, with four-five moderately long and several short hairs. Occipital margin strongly concave; edged with yellowish-brown band and dark-brown blotch; a long hair arising from near the blotch. On the ventral aspect, chitinous framework for support of mandibles continued forward to the anterior margin of the head, running downwards along inner border of the antennal fossae and then to the gular region enclosing faintly coloured plate with three moderately long fine hairs on each side; oesophageal glands and sclerite well developed. Antennae 5-jointed; I joint short, squat and quadrate; II joint obliquely companulate, with a stout basal stalk, fitting into joint I, apical half goblet-shaped; III joint calyciform with short, narrow peduncle placed apically on one side of the middle line of joint II; IV joint obliquely trough-shaped, narrow basally to fit uniformly in joint III and broad apically to accommodate obliquely hemispherical joint V, which is narrowly excavated at the apex, furnished with numerous tactile hairs; distribution of visible hairs is shown in figure.

Pro-thorax short, anterior portion deeply inserted under the occipital margin; anterior lateral margin concave; lateral angles acute, each with a short and a long hair; posterior-lateral margins slightly concave, bearing one short and a long hair; posterior margin fairly convex with about six long hairs, transverse bar distinct with a small, indistinctly visible hair on its ends; longitudinal bars well built.

¹ *Upak* is the vernacular name of the Common Hawk Cuckoo.

Meso-thorax distinct, lateral plate narrow. Meta-thorax diverging posteriorly, lateral margins straight, each with 1-2 spines; posterior lateral angles bearing one



TEXT-FIG. 12. *Cuculiphilus upak*, sp. nov.: (a) dorsal and ventral aspects of female (b) ventral aspect of a portion of head (enlarged), (c) ventral aspect of posterior femora (enlarged), and (d) portion of III-IV sternites showing combs of hairs (enlarged).

long and a short hair; posterior margin convexo-concave, with four long and a short hair. Legs concolorous with the body, rather short, with well pigmented outer and inner margins; hind femora (Text-fig. 12c) with several short hairs on outer and inner chitin; ventrum furnished with four combs of minute stiff hairs and several hairs, not sufficient to form a brush, scattered towards the tibial joint. Pro-sternum with a circular, central perforation; coxal plates almost touching each other. Meso- and meta-sternites well separated; meso-sternum well chitinized anteriorly and merging into pericoxal plates; meta-sternum faintly chitinized with two fine hairs.

Abdomen ovate, widest in the middle; segments almost equal in length, lateral margins convex; posterior angles with one long and several, ventrally arising short hairs; posterior margin of segments I-IV truncate, those of V-VIII slightly concave, each bearing a row of 8-10 fine long hairs; last segment posteriorly truncate, with two long hairs on each side and several short hairs between them. Ventral surface of each segment with three irregular rows of fine hairs, sternites III-IV (Text-fig. 12d)

each with three broad combs of spines on each side. Pleural plates darker, artistically pigmented on II-VIII and simple on I, each with several short hairs, scattered irregularly. Genital plate distinct, furnished with about 24 marginal hairs; a fringe of fine hairs beyond it which merges into the general chaetotaxy.

Male: not available.

Measurements (mm.) of Cuculiphilus upak sp. nov.

Female	(Holotype).		(Paratype).	
	Length.	Breadth.	Length.	Breadth.
Total ..	1.298	....	1.420	....
Head ..	0.310	0.604	0.290	0.550
Pro-thorax ..	0.129	0.320	0.120	0.340
Ptero-thorax ..	0.137	0.450	0.140	0.400
Abdomen ..	0.740	0.670	0.870	0.650
Head-index ..	2.006		1.896	

Holotype: A female from Lyalpur, 24.iv.1930, on slide No. MA. 038 ex the Common Hawk Cuckoo, *Hierococcyx varius* Vahl.; *Paratype*: A female (same data as above).

This species agrees with *Cuculiphilus fasciatus* (Scopoli), differences, however, exist in the size of the body, shape of the head and the thorax, and general chaetotaxy particularly ventral combs of hairs.

23. *Cuculiphilus pupiya*¹ sp. nov.

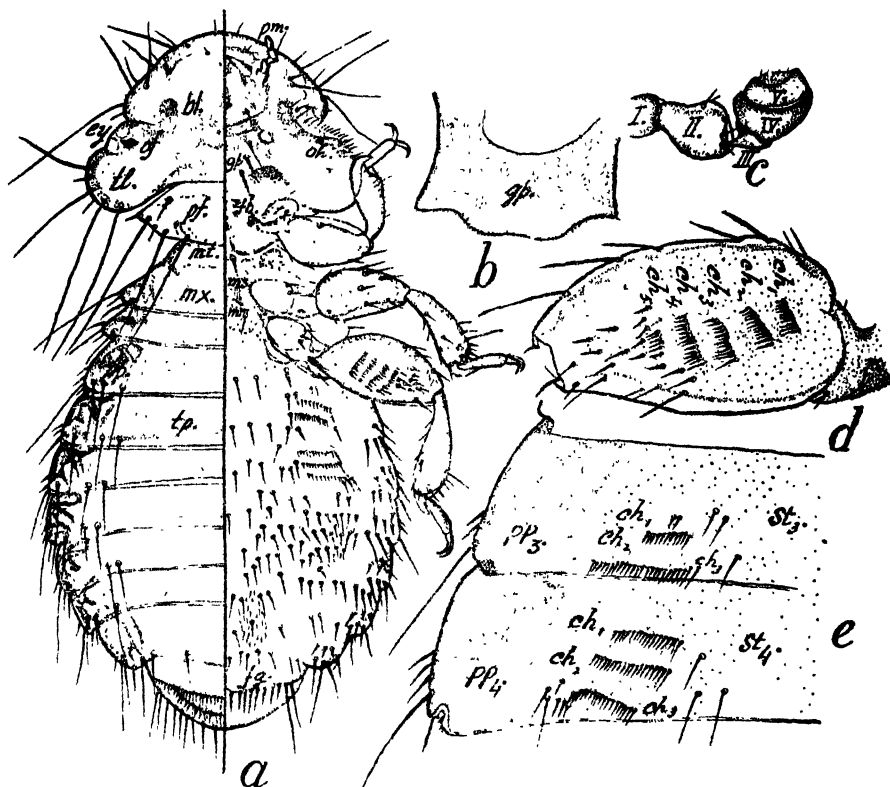
Female (Text-fig. 13a): body short and broad, yellowish-brown, with dark-brown markings on head, thorax and abdomen.

Head yellowish-brown, somewhat lunate; front broadly rounded, with several fine hairs and five long hairs, one on the lateral angle being exceptionally long; ocular slit narrow, deep, backed up by brown blotch; eyes prominent, almost flat; ocular fleck prominent, black, nearly quadrate, medially interrupted; temples flatly broad, marginally rounded, each bearing four long and several short hairs, occipital margin strongly concave, edged with brown band and deep-brown blotch, bare. Ventral framework of the head strongly built; antennal fossae backed up by a highly chitinized area. Gular region with a pigmented shield (Text-fig. 13b), bearing three long lateral hairs; oesophageal sclerite and glands well developed. Antennae (Text-fig. 13c) 5-segmented, similar to *Cuculiphilus upak* sp. nov. (*vide supra*).

Pro-thorax short, anterior margin deeply inserted under the occipital margin; lateral angles produced, each with a short and a long hair; posterior-lateral margins slightly concave, with a short and a long hair; posterior margin slightly convex with a long hair on each side, arising from a highly chitinized bar which runs to the front and meets transverse bar, a small seta at the point of junction. Meso-thorax short, distinct, lateral plates strongly built, running a short distance anteriorly. Meta-thorax about as long as the abdominal segments; lateral margin slightly concave, diverging posteriorly, each with a short and a long hair; posterior margin almost straight with one hair towards the lateral angles. Legs concolorous with the body, rather short, with well pigmented outer and inner femoral and tibial chitin; hind femora (Text-fig. 13d) with five subequal combs of short hairs and

¹ *Pupiya* is the vernacular name for the Indian Pied Crested Cuckoo.

several hairs irregularly scattered towards the tibial joint. Pro-sternal plate trapezoidal, with a central, oblong pit and a short hair on the anterior margin; coxal



TEXT-FIG. 13. *Cuculiphilus pupiya*, sp. nov.: (a) dorsal and ventral aspects of female, (b) gular sclerite (enlarged), (c) antenna of female (enlarged), (d) ventral aspect of posterior femora showing chaetotaxy (enlarged), and (e) portion of III-IV abdominal sternites showing combs of hairs (enlarged).

plates well apart from each other. Meso- and meta-thoracic sternites distinctly separated, meso-sternite highly chitinized, pericoxal plates with two short anterior hairs; meta-sternite quadrangular, faintly pigmented, bearing fine hairs.

Abdomen broadly ovate, widest at IV-V segment and then gradually narrowing to the posterior; segment I narrow, segment II longest, others subequal; posterior angles with 1-2 long hairs; segments I-VII with almost straight posterior margins, segment VIII with convex posterior margin; tergites yellowish-brown, darker towards the lateral ends, entire; segment I bearing one, while others with three sub-marginal long hairs, median bare; segment IX rounded posteriorly, furnished with about twenty long hairs. Ventral surface of each segment with transverse plates, each bearing two rows of hairs, III sternite with two and IV sternite with three broad combs of spines on each side (Text-fig. 13e) indistinct patches of short hairs, almost merging with general chaetotaxy on each side of V-VII sternites. Pleural plates, dark in colour; well developed on I-VIII segments, characteristically designed on II-VIII; each with several short setae. Genital plate distinct, lying across IX sternite, furnished with about two dozen marginal hairs. A fringe of fine hairs on the posterior tip.

Male: not available.

Measurements (mm.) of Cuculiphilus pupiya sp. nov.

Female.	(Holotype).		(Paratype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.544	..	1.48	..
Head	0.321	0.55	0.29	0.57
Pro-thorax	0.156	0.35	0.16	0.36
Ptero-thorax	0.131	0.46	0.15	0.44
Abdomen	0.936	0.69	0.89	0.66
Head-index	1.713		1.956	

Holotype: A female from Lyallpur, 22.vi.1929, on slide No. MA. 039 ex the Indian Pied Crested Cuckoo, *Clamator j. jacobinus* (Bodd.); *Paratype*: A female (same data as above).

This species closely resembles *Cuculiphilus upak* sp. nov. (*vide supra*), but differs in the shape of the head, general chaetotaxy and ventral combs of hairs.

ULULOECCUS subgen. nov.

Small sized species; head comparatively short, somewhat lunate in shape; front parabolic, sides swollen; lateral margins with a slight notch and distinct slit before the eyes; chitinous framework for support of mandibles continued forwards to the anterior margin of the head and then curving downwards and backwards along the antennal fossae to the gular plate; antennae 4-jointed, short, not projecting, of the shape shown in text-figure, oesophageal sclerite and glands well built; gular plate squarish. Thorax normal, ptero-thorax very short, meso-notum separated from meta-notum, thoracic sternites well formed; legs normal, posterior femora with three combs of minute spines on the ventral surface. Abdomen elliptical, apically truncate; transverse bands pale-yellow, extending to pleurites; segments I-VIII with two rows of short hairs; sternal plates hairy, I-VII with three transverse rows, VIII-IX with two such rows of short hairs; two broad combs of spines upon each side of III sternite, sternites IV-VII each with a patch of minute hairs, merging more or less with the general chaetotaxy.

Species occurring, as far as known, only upon owls (Strigiformes).

Type of the subgenus: *Ululoeccus panjabensis*, sp. nov. (*vide infra*) ex the Northern Spotted Owlet, *Athene brama indica* (Frankl.).

Ululoeccus resembles *Cuculiphilus* Uchida in apparent body structures, but is widely different from it in certain characters of sub-generic importance, detailed below.

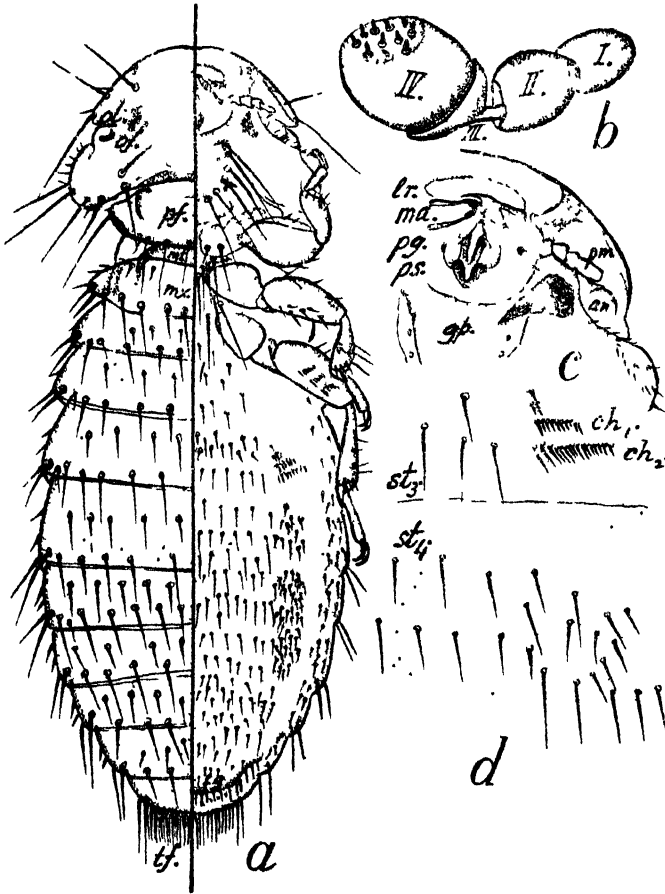
Colpocephalum painei McGregor from the Screech Owl, *Otus asio maccallicephalum*, which was described as a curious *Colpocephalum* by the author, and included in *Cuculiphilus* by Uchida (1926), seems to be a member of this new subgenus.

24. Cuculiphilus (Ululoeccus) panjabensis sp. nov.

Female (Text-fig. 14a): body short and broad, pale-yellow with yellowish-brown markings on head.

Head almost twice as broad as long; front rounded, anterior margin somewhat squat, with a slight concavity on the meson, lateral margins slightly swollen, with yellowish-brown blotch immediately behind, bearing two long and a short marginal hair; one long dorsal hair, submarginal in position; ocular slit fairly deep, backed up with brown blotch; eyes prominent, flat, with a single cornea; ocular fleck

kidney shaped; temples expanded, margins rounded, each bearing four long and several short hairs, numerous short marginal hairs irregularly scattered on the ventrum; occipital margin concave, edged with yellowish-brown band and fuscous-brown lateral blotches, chaetotaxy scarce, only one marginal and one submarginal hair, near the occipital blotch. On the ventrum, chitinous framework for support of mandibles well developed, continued as far as on each side of labrum and anterior margin of the head, then running backwards along the lateral margins of the forehead; oesophageal sclerite and glands well developed; gular plate characteristic, broadly conical, tapering gradually to posterior end, well chitinized and continued as far as the pro-thoracic sternum, furnished with 4-6 long hairs on the lateral margin. Antennae (Text-fig. 14b) prominent. I joint bead-shaped; II joint similar to I but robust; III joint calyciform, with short stalk, immediately inserted to one side of segment II; IV joint dorso-ventrally flattened orbit, tilted to one side, subapical depression well marked, furnished with tactile setae. Antennal fossae well developed, deep, backed up by a strongly pigmented chitin, which continues as far as the gular plate, lateral margin of ventral plate with several short hairs.



TEXT-FIG. 14. *Aculiphilus (Ululocerus) panjabensis*, sp. nov. (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) ventral aspect of a portion of head (enlarged), and (d) III-IV abdominal sternites showing chaetotaxy (enlarged).

Pro-thorax short, broad; anterior margins concave, lateral angles obtuse, each with a short spine and a long hair; posterior-lateral margins slightly concave with a short and a long hair; posterior margin slightly convex, with a short and three long hairs on each half; a longitudinal median papilla present; a transverse yellowish bar between the marginal longitudinal bands. Meso-thorax short and narrow distinctly separated from meta-thorax. Meta-thorax trapezoidal in shape, lateral margins straight or slightly convex, diverging posteriorly, each with several marginal and submarginal spines; posterior lateral angles bearing one long and a short hair; posterior margin with about ten long hairs. Pro-sternum with large central portion, lateral bars running along the anterior coxal margin; frontal coxae enlarged, almost touching each other in the middle; meso- and meta-sternites short, bearing numerous long hairs. Legs concolorous with the body, outer margins well chitinated; posterior femora with three ventral combs of minute hairs.

Abdomen elliptical, widest at the IV segment, segments subequal, latero-posterior angles projecting, each bearing two long hairs, posterior margins I-IV straight, those of V-VIII concave, each bearing 10-12 long hairs, dorsal surface of I-VIII segments bearing another row of weak hairs; last segment narrow, almost truncate, bearing two long hairs on each side and fringe of fine hairs between them. Abdominal sternites I-VII with three transverse rows of short hairs, sternites VIII-IX with two such rows of weak hairs; two broad combs of spines on each side of third sternite (Text-fig. 14d). Sternites IV-VII with a patch of numerous short hairs, merging more or less with the general chaetotaxy. Pleural plates distinct, each with several hairs. Genital plate lying across IX sternite, furnished with marginal row of hairs.

Male: not available.

Measurements (mm.): Length × Breadth.

Holotype (female): Total 1.561×0.641 , head 0.271×0.534 , pro-thorax 0.145×0.359 , ptero-thorax 0.126×0.427 , abdomen 1.019×0.641 , head index 1.97.

Holotype: A female from Lyallpur, 23.xi.1931, on slide No. MA. 043 ex the Northern Spotted Owllet, *Athene brama indica* (Frankl.). *Paratype*: two females (same data as above).

This species, apparently, not very closely related to any form which has so far been described or figured from specimens taken off the owls (Strigiformes).

25. *Cuculiphilus* (*Ululoecus*) sp.

One immature specimen was obtained, ex the Indian Barn Owl, *Tyto alba strepens* (Hart.), shot in Lyallpur, 11.ix.1931.

26. *Cuculiphilus* (*Ululoecus*) sp.

One globular, mutilated female, ex the Indian Great Horned Owl, *Bubo bubo bengalensis* (Frankl.), shot in Gurdaspur, 8.ii.1928.

27. *Ardeiphilus trochioxus* (Nitzsch).

1838, *Colpocephalum trochioxum*, Nitzsch, in *Burmeisters' Handbuch der Ento.*, II, p. 438.

This species was first described from the Bittern, *Botaurus s. stellaris* (Linn.), and since then has been recorded from various other herons from different parts of the world. The following of its hosts also occur within our Faunistic limits: The Purple Heron, *Ardea purpurea* Linn.; the Common Indian Pond Heron, *Ardeola grayii* (Sykes); and the Bittern, *Botaurus s. stellaris* (Linn.).

The specimens referred to here, were collected from the Indian Pond Heron, *Ardeola grayii* (Sykes), at Lyallpur 1.ix.1933.

Measurements (mm.): Length \times Breadth.

3 females: Total 2.280-2.336 \times 1.116-1.126, head 0.398-0.408 \times 0.823-0.835, thorax 0.472-0.582 \times 0.728-0.747, abdomen 1.300-1.456 \times 1.116-1.126, head-index 2.017-2.097.

Piaget (1880) gave the measurements of female and male as 2.6-2.7 mm. \times 1.13 mm. and 2.1-2.2 mm. \times 0.95 mm. respectively, while Qadri (1935) gave the measurements of female of *Cuculiphilus mirzai* Qadri (Synonym) as 2.5 mm. \times 1.025 mm. According to these measurements the head-index calculated = 1.717, 1.875 and 1.631 respectively.

28. *Allocolpocephalum subaequale* (Nitzsch).

1838, *Colpocephalum subaequale*, Nitzsch, Burmeisters' *Handbuch der Ent.*, 11, p. 438.

This is a long known species of Mallophaga infesting crows and is cosmopolitan in its distribution. This species was first described from the European Ravan, *Corvus corax* Linn. and the Rook, *Corvus frugilegus* Linn. Kellogg and Paine (1914) recorded it *ex Corvus insolens* from Burma and *ex Corvus s. splendens* from Calcutta.

The specimens referred to below were collected from the Punjab Raven, *Corvus corax laurencei* Hume; and the Common House Crow, *Corvus s. splendens* Vieill; from various parts in the Punjab.

Measurements (mm.): Length \times Breadth.

10 females: Total 1.42-1.51 \times 0.59-0.62, head 0.28 \times 0.47-0.52, thorax 0.30-0.32 \times 0.45-0.48, abdomen 0.84-0.95 \times 0.59-0.62, head-index 1.671-1.857.

Piaget (1880) gave the measurements of female and male as 1.5-1.6 mm. \times 0.58 mm. and 1.2 mm. \times 0.45 mm. respectively while Kellogg's female measured 1.53 mm. \times 0.63 mm. According to these measurements the head-index calculated = 1.911, 1.387 and 1.613 respectively.

Cesare Conci, April 1942, erected a new Genus *Corvocolpocephalum* for this species. This is apparently a synonym of *Allocolpocephalum* Qadri (1939).

PICUSPHILUS subgen. nov.

The old unwieldy and complex group of Colpocephalids (*Colpocephalum* Nitzsch) has been greatly simplified, by taking out a number of accurately defined, distinct forms and grouping them into small and compact genera. Uchida (1926) was, probably, the pioneer worker in this direction. He separated the genus *Cuculiphilus* for species mostly occurring upon Cuculiformes, Coraciiformes and Strigiformes. The characters of this subgenus include mainly 3-4 combs of spines upon ventral surface of the posterior femora and 1-3 combs upon each side of certain abdominal sternites; lateral margin of the head with slit before the eyes; and genitalia of male characteristic, very much different from *Ciconiphilus* Bedford.

The specimens before me, from the Scally-bellied Green Wood-pecker, resemble the species included in *Cuculiphilus* Uchida (1926), but are readily distinguished by certain important characters necessitating their separation from this genus. The author deems it necessary to suggest a new sub-genus for species infesting Piciformes.

Description of the sub-genus.—Body short, elongate; with the tergites, sternites and pleural plates well formed. Head less than twice as broad as long; forehead considerably narrower than hindhead, parabolic; lateral margins with a distinct

notch in front of the eyes; temples expanded, rounded; ocular blotch distinct, gular plate well developed; antennae 4-jointed, projecting; oesophageal glands and sclerite vestigial.

Pro-thorax short, with acute wings; meso-notum short, completely fused with meta-notum. Legs normal; posterior femora with three combs of short spines on the venter.

Abdomen elongated; tergal, sternal and para-tergal plates distinct; tergites with two transverse rows of hairs; sternites very hairy, usually with 2-3 rows of hairs; III sternite with two combs of stiff hairs on either side, set diagonally to the posterior margin.

Male genitalia distinctly different from *Cuculiphilus* Uchida (1926). Basal plate long and slender, reaching the posterior margin of II abdominal segment, expanded towards the apex and articulating with a flat rounded lamina; parameres short, incurved and pointed; preputial sac beset with recurved hooks.

Type of the subgenus: Picusphilus tirkhan sp. nov. (*vide infra*) ex the Himalayan Scally-bellied Green Wood-pecker, *Picus s. squamatus* Vigors.

29. *Cuculiphilus (Picusphilus) tirkhan*¹ sp. nov.

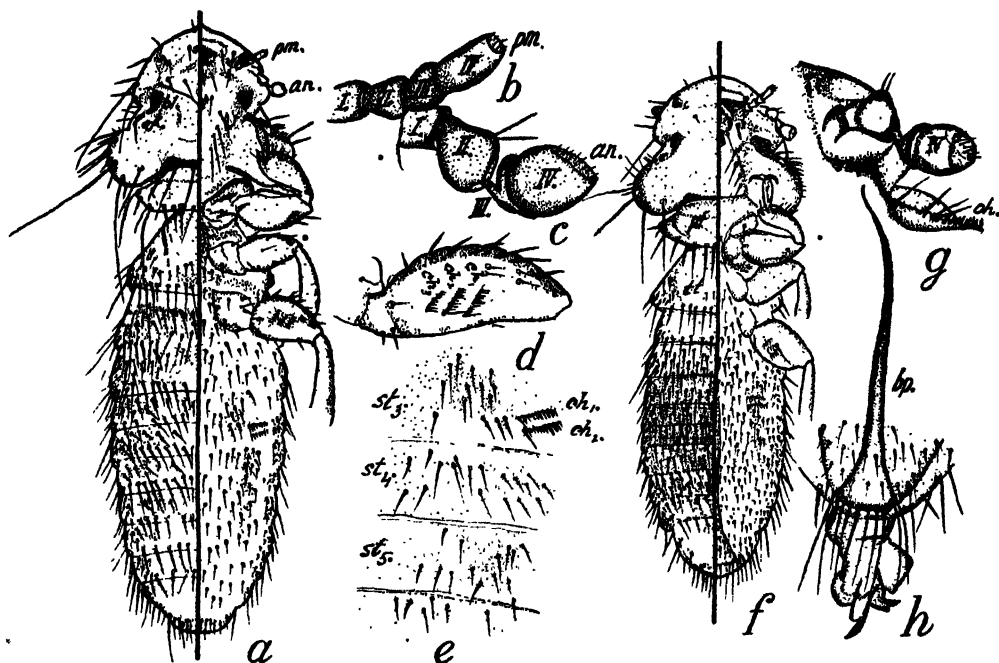
Female (Text-fig. 15a): body small, elongate; pale-brownish, with dark-brown body markings.

Head slightly wider than long; front rounded with a median angulation; a short hair on each side of the angulation, three subequal hairs on the lateral margin, and two long and a short hair on the lateral angle, three short and a long hair on the dorsal surface disposed of as shown in figure, ocular emargination a shallow notch, backed with a yellowish-brown blotch. Eyes almost flat, large, with a quadrangular fleck and a short hair arising posteriorly; temples expanded, margins rounded, each bearing several long pustulated hairs and several short hairs, a long pustulated hair submarginal in origin. Occipital margin concave, edged with yellowish-brown band and dark-brown occipital blotch, bearing two long hairs on each half. Ventral aspect of head with well chitinized, yellowish-brown, framework for support of mandibles; oesophageal sclerite and glands well developed; gular region with distinct plate, bearing four long hairs; antennal fossae extensive, backed up with a chitinized blotch about the base of ocular notch, and another near the palpus, which continues to the front. Antennae (Text-fig. 15c) projecting, 4-jointed; scape quadrate; II joint pyriform, outer margin dilated to one side; III joint oblique calyciform, stalk inserted apically on one side of segment II; IV joint cylindrical, squat, resting obliquely in shallow cavity of the calyx, subapically truncate; visible chaetotaxy disposed of as in figure. Ventral temporal plate with numerous short stiff marginal hairs.

Pro-thorax short with protruded wings, lateral angles acute, each with a long hair; posterior lateral margins slightly concave or straight, bearing two short and a long hair; posterior margin almost straight with four hairs on each side of a medial protuberance; transverse bar yellowish, distinct; longitudinal band well built, yellowish-brown; a short hair at the junction of the two, a median furrow running from the transverse bar to the posterior papilla. Meso-thorax narrow, not well separated; meta-thorax short, broad, with slightly convex, widely diverging sides bearing several setae; posterior lateral angles acute; posterior margin almost straight with numerous long hairs, dorsal surface with numerous short hairs; lateral posterior region dark-brown, extending to the narrow lateral band and dorsally to the broad tergal plates. Pro-sternum largely occupied by the well developed coxal plates which touch each other in the middle. Ptero-sternum with several long hairs. Legs concolorous with the body; outer margins highly

¹ *Tirkhan* is the Punjabi name for the Himalayan Scally-bellied Green Wood-pecker.

chitinized, dark-brown; posterior femora (Text-fig. 15d) with three ventral combs of hairs, each composed of about 10, 14 and 16 hairs respectively.



TEXT-FIG. 15. *Cuculiphilus (Picusophilus) tirikhan*, sp. nov.: (a) dorsal and ventral aspects of female, (b) maxillary palp of female (enlarged), (c) antenna of female (enlarged), (d) posterior femora showing ventral combs of hairs (enlarged), (e) III-IV abdominal sternites showing chaetotaxy (enlarged), (f) dorsal and ventral aspects of male, (g) ventral aspect of a portion of head (enlarged), and (h) male genital armature (enlarged).

Abdomen elongate, broadest at the IV segment; length of segments subequal: lateral margins with small setae; posterior lateral angles bearing two long hairs; tergites well chitinized, with two transverse rows of hairs, confined to the highly pigmented lateral portion, and one row on the faintly coloured medial portion of I-VI tergites; VII-VIII tergites with weak second row of hairs; IX segment bearing several short and a long hair on each side of a fringe of colourless fine hairs. Abdominal sternites with 2-3 irregular rows of short hairs; III sternite (Text-fig. 15e) with two combs of stiff hairs on either side, set diagonally to the posterior margin. Pleural plates distinct, each with numerous irregularly arranged short hairs.

Male (Text-fig. 15f): similar to female, but smaller; abdomen somewhat short, rounded posteriorly, fringe of fine hairs wanting. Genitalia (Text-fig. 15h) slender, long, reaching the posterior margin of II abdominal segment; distally set with a flat plate, lateral margins well chitinized; parameres slender. An exerted penis is shown in the figure.

Holotype: A female from Kulu (Kangra Valley), 6.x.1939, on slide No. MA. 037, ex the Himalayan Scally-bellied Green Wood-pecker, *Picus s. squamatus* Vigors; *Allotype*: A male; *Paratypes*: Two females (same data as above).

It is allied to *Colpocephalum inaequale* Nitzsch, but differs in size, shape of the body, tergal markings and general chaetotaxy. This species seems to be a member of this group.

Measurements (mm.) of Cuculiphilus (Picusphilus) tirkha sp. nov.

	Female (Holotype).		2 females (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.487	..	1.428-1.508	....	1.268	..
Head ..	0.333	0.463	0.306-0.315	0.444-0.463	0.296	0.416
Pro-thorax ..	0.139	0.324	0.129-0.157	0.315-0.324	0.139	0.296
Ptero-thorax ..	0.154	0.416	0.155-0.188	0.398-0.416	0.185	0.287
Abdomen ..	0.866	0.555	0.805-0.898	0.491-0.555	0.648	0.450
Head-index ..	1.39		1.451-1.469		1.405	

Sub-family: MENOPONINAE

30. *Menopon phaeostomum* (Nitzsch).

1866, *Menopon phaeostomum*, Nitzsch, *Zeit f. ges. Nat.*, XXVIII, p. 391.

This is one of the best known *Menopon* and has been recorded from *Pavo cristatus* Linn., from various parts of the world.

Several specimens were obtained by me from the type-host, *Pavo cristatus* Linn.; from Attari (near Lahore), 9.vi.1935.

Measurements (mm.) of Menopon phaeostomum Nitzsch.

	Female.		Male.	
	Length.	Breadth.	Length.	Breadth.
Total	2.691	..	1.738	..
Head	0.468	0.844	0.365	0.708
Pro-thorax ..	0.327	0.698	0.261	0.573
Ptero-thorax ..	0.271	0.729	0.156	0.615
Abdomen	1.625	0.958	0.956	0.739
Head-index ..	1.803		1.939	

31. *Menopon gallinae* (Linn.).

1758, *Pediculus gallinae*, Linnaeus, *Syst. Nat.*, p. 613.

This familiar species has been recorded from practically all over the world on the Domestic Fowl, *Gallus g. domesticus* Linn. It is an active species and is frequently recorded wandering about on roosts and elsewhere in chicken houses. It is also known to pass readily to other barn-yard fowls, viz. pigeons, ducks, guinea-fowls, turkeys, etc., cattles, horses and dogs. It is commonly found in India and it is the most abundant of all the species infesting House hen in the Punjab.

Denny (1842) gave the length of female and male as $\frac{3}{4}$ " and $\frac{1}{2}$ ", i.e., 1.905 mm. and 1.27 mm. respectively.

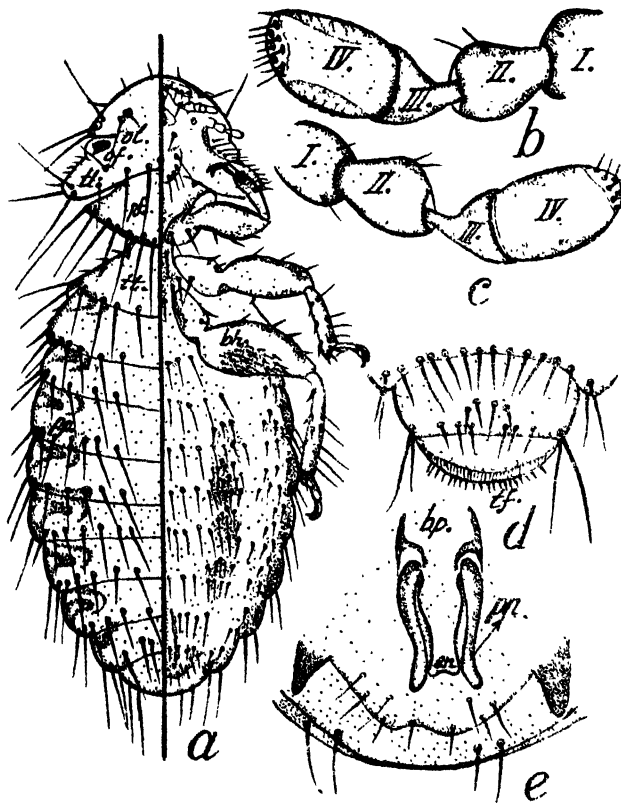
Measurements (mm.) of Menopon gallinae (Linn.).

	Female.		Male.	
	Length.	Breadth.	Length.	Breadth.
Total	1.75	..	1.8-1.90	..
Head	0.31	0.47	0.32	0.46
Thorax	0.35	0.49	0.32	0.49
Abdomen	1.10	0.72	1.26	0.68
Head-index	1.516		1.439	

32. *Menopon interpositus* sp. nov.

Male (Text-fig. 16a): body small, almost twice as long as broad, pale-yellow, with slightly deeply coloured body markings.

Head short, broad; lateral angles acute, front parabolic with three short marginal hairs and three long hairs on the angles in front of shallow ocular emargination, a long and a short hair on each side of dorsum; ocular emargination distinct, but shallow, continued into a slit just before the eyes; eyes large and flat, with a



TEXT-FIG. 16. *Menopon interpositus*, sp. nov.: (a) dorsal and ventral aspects of male, (b) antenna of male (enlarged), (c) antenna of female (enlarged), (d) tip of abdomen of female (enlarged), and (e) male genital armature (enlarged).

pitchy, almost quadrate ocular fleck; ocular fringe distinct, composed of several short, curved hairs, continuous on the ventral lateral expansion of head. Temples narrow, expanded, reclined towards occiput, rounded marginally, each with three long and several short marginal hairs; occipital margin fairly concave, bearing three submarginal hairs on each half, occipital blotch distinct. On the ventrum mandibles situated a short distance behind the anterior margin; labrum narrow with several short hairs; oesophageal sclerite and glands distinctly visible, modified; chitinous framework for support of mandibles well developed, continued as far as the anterior margin of the head. Gular plate quadrate, bearing four long hairs on each side. Antennae (Text-fig. 16b) prominent, projecting beyond the antennal sinuses, 4-jointed; scape squat, II joint subpyriform; III joint narrow and pedunculate basally and flattened anteriorly to accommodate last segment, which is cylindrical and bearing several short hairs on the tip.

Pro-thorax large, protruded; lateral angles acute, each with a long hair; posterior margin convex with six long hairs on each half; transverse longitudinal bar pale and distinct; intercoxal plates showing through. Meso-thorax very narrow, completely fused with meta-thorax. Ptero-thorax short, broad, with strongly divergent, straight lateral margins, each bearing three short hairs; lateral angles acute, bearing two long hairs; posterior margin convex, bearing four long hairs on each side. Legs concolorous with the body, outer margin chitinized; hind femora with a group of short ventral hairs. Pro-sternum completely reduced, largely covered by the plate-like coxae of fore-legs. Ptero-sternum short, beset with several hairs as shown in text-figure.

Abdomen elliptical, widest at the IV segment; length of the segments nearly subequal; posterior angles produced; posterior margins I-IV slightly convex, V-VI nearly straight, VII-VIII nearly concave each bearing a submarginal row of long hairs, last segment flatly rounded with two long hairs on each side. Ventral surface of each abdominal sternite with transverse row of short hairs, a distinct patch of numerous short hairs on each side of IV sternite; V-VI sternites with indistinct patches of spines merging with general chaetotaxy. Pleural plates distinct, with several irregularly scattered short setae. Last segment (Text-fig. 16c) with distinct genital plate, bearing five short hairs on either side. Genitalia (Text-fig. 16e) simple more or less of general type, closely resembling that of *Menopon gallinae* (Linn.); basal plate short, slightly chitinized; parameres long, club-shaped with broad outwardly curved distal ends; endomeral plate oblong with well chitinized, slender lateral margins, posterior margin concave.

Female: similar to male, larger in size and hairy; last segment (Text-fig. 16d) with numerous short hairs along the margin.

Measurements (mm.) of Menopon interpositus sp. nov.

	Male (Holotype).		5 Males (Paratype).		8 Females (Paratype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.225	..	1.187-1.284	....	1.717-2.048	....
Head ..	0.264	0.491	0.283-0.301	0.500-0.519	0.302-0.377	0.622-0.645
Pro-thorax	0.169	0.349	0.161-0.169	0.330-0.339	0.208-0.236	0.434-0.491
Ptero-thorax	0.151	0.377	0.122-0.161	0.349-0.424	0.169-0.255	0.538-0.613
Abdomen ..	0.641	0.566	0.613-0.661	0.481-0.528	1.038-1.255	0.811-0.962
Head-index	1.858		1.724-1.767		1.676-2.06	

Holotype: A male mounted on slide No. MA. 057H from Lyallpur, 4.vii.1928, ex the Northern Grey Partridge, *Francolinus pondicerianus interpositus* Hart.

Allotype: A female on slide No. MA. 057A; *Paratypes*: several females and males (same data as above).

This species closely resembles *Menopon gallinae* (Linn.), important differences, however, exist in the shape of the head, last abdominal segment and in dorsal chaetotaxy.

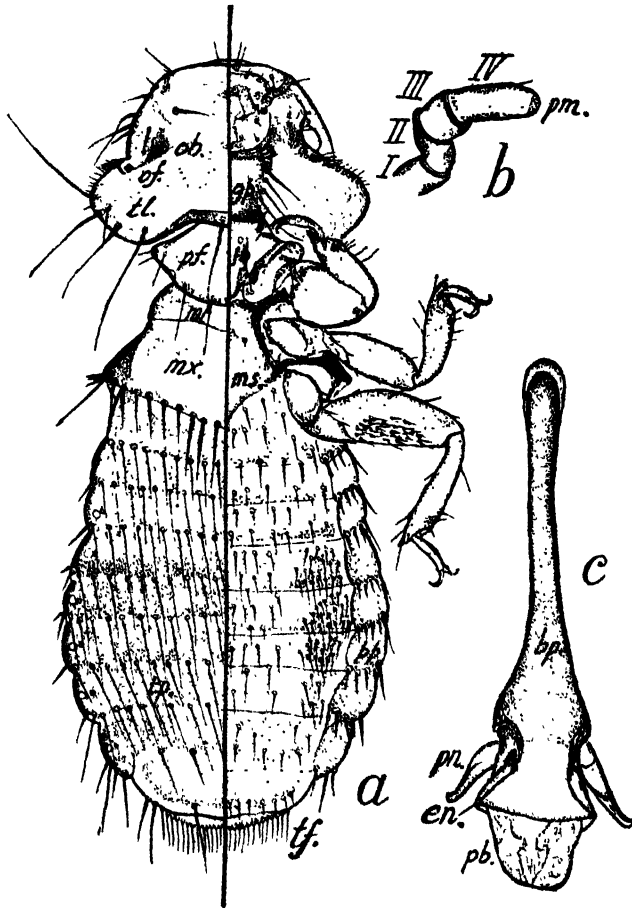
33. *Menopon* sp.

One immature specimen was taken off the Common Northern Chukor, *Alectoris graeca pallescens* (Hume.), shot in Kulu (Kangra Valley), 9.x.1939.

34. *Neomenopon baktitar*¹ sp. nov.

Female (Text-fig. 17a): body moderately robust, fuscous-brown with pitchy-brown markings on head, thorax and abdomen.

Head moderately broad, being slightly less than twice as wide across the temples as long; front broadly rounded, nearly truncate; one marginal and one submarginal short hair on each side of the middle line, six hairs of various lengths on the lateral margins, which are swollen; two hairs on each side of the dorsum;



TEXT-FIG. 17. *Neomenopon baktitar*, sp. nov.: (a) dorsal and ventral aspects of female, (b) maxillary palp (enlarged), and (c) male genital armature (enlarged).

¹ *Bakt-titar* is the vernacular name for the Indian Common Sand-Grouse.

lateral dorsal margins of head continuous with the eyes; eyes rounded, single cornea; ocular fleck black, almost square, backed by a pitchy-brown area near the anterior end of the ventral continuation of temporal margin; clypeal blotch present on each side of the head. Temples expanded, bluntly angular posteriorly; anterior margins with ocular fringe of stiff hairs, lateral margins flatly rounded with four long pustulated hairs, a smaller submarginal hair and several short hairs; temporal band pitchy-brown; occipital margin concave, occipital band fused with temporal band; occipital blotch distinct; one long hair on each side of the middle. Ventrum with highly chitinized framework for support of mandibles, continued to the anterior margin of clypeus, thence running to the inner border of the antennary fossae; a band connecting the two across the well developed, quadrate, gular-plate, which is laterally beset with five long hairs; oesophageal sclerite and glands well developed, antennae 4-jointed, concealed; scape short; II joint subpyriform with expanded inner margin, expansion furnished with two short hairs; III joint squat, flattened anteriorly, pedunculate basally; IV joint truncate, squat, well placed in the saucer behind. Palpi (Text-fig. 17b) with longest apical segment, II joint shortest, III and IV subequal.

Pro-thorax winged; anterior margin well inserted beneath the head; lateral angles acute, with two short spines; lateral margins almost confluent with the posterior margin, strongly convex, two long hairs on the margin; transverse bar faint, longitudinal bars highly developed, a short hair at the junction of the two. Meso-thorax distinct, narrow, lateral band pitchy-brown, continued to the anterior margin. Meta-thorax with nearly straight; lateral margins, widely diverging posteriorly; posterior lateral angles acute with two spines; posterior margin angulate on the abdomen, angle projecting backwards as far as the imaginary line connecting posterior angles of I abdominal segment, beset with about 10 hairs on each side of the angle; posterior lateral plate dark-brown. Legs faintly pigmented than the body, marginal bands dark-brown; posterior femora with a thick ventral patch of stiff hairs. Pro-sternal plate well developed, quadrate anteriorly with a triangular piece added to the base, lateral arms arising from the junction and running forwards along the margin of the plate-like coxae of the foot-jaws. Meso- and Meta-sternum separated; mesal plate rather small, almost quadrate; meta-sternal plate four-sided, beset with several short hairs; pericoxal plates well chitinized.

Abdomen ovate, being rather orbicular beyond segment III; widest at the VI segment; length of segments I-VIII nearly subequal, segment IX rather long; posterior angles of II-III segments with one short hair, IV-VI segments with two short hairs, VII segment with one short and one long hair, VIII segment with three long hairs; posterior margin of I-III segments convex, those of IV-VII almost straight, I-VII segments bearing a transverse row of numerous hairs, segment VIII with four hairs, segment IX truncate with two long hairs on each side of a fringe of fine hairs and a long hair a short distance towards the middle; tergal-plates distinct, transverse bands, entire, deep-brown, slightly darker laterally and with yellowish-brown intersegmental areas. Abdominal sternites with two irregular, transverse rows of short hairs; each side of the sternites IV-VI with distinct patches of short hairs, sternite VII with indistinct patch of setae merging in the general chaetotaxy. Pleural plates distinct, posterior margins beset with stiff spines.

Male: similar to female, narrow and ovate; last segment broadly rounded, with a long hair on each side and several short hairs between. Genitalia (Text-fig. 17c) with basal plate long and slender, reaching from the posterior margin of IV segment to the end of the last segment, apex expanded; paramere short, outwardly recurved; at the apex of the basal plate a well chitinized quadrate plate with well built outer endomeres.

Holotype: A female from Lyallpur, 7.ix.1933, on slide No. MA. 050 ex the Indian Common Sand-Grouse, *Pterocles exustus erlangeri* Neum.; *Allotype*: A male (same data as in table following).

Measurements (mm.) of Neomenopon baktitar sp. nov.

	Female (Holotype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.766	..	1.503	..
Head	0.388	0.612	0.339	0.566
Pro-thorax ..	0.194	0.388	0.194	0.359
Ptero-thorax ..	0.311	0.534	0.291	0.446
Abdomen	0.873	0.679	0.679	0.526
Head-index	1.577		1.669	

The genus *Neomenopon* Bedford hitherto included only the species *Neomenopon pteroclorus* Bedf. from *Pteroclorus namaqua*. The one described here is distinguished from *N. pteroclorus* by (i) shape of the head, pro-thorax, ptero-thorax and abdomen and (ii) general chaetotaxy.

35. *Trinoton querquedulae* (Linn.).

1758, *Pediculus querquedulae*, Linnaeus, *Syst. Nat.*, p. 613.

This is one of the long known parasites, most commonly infesting various species of ducks and has been recorded from practically all parts of the world. The following of its recorded hosts are also found within Indian limits: the Mallard, *Anas platyrhynchos* Linn.; the White-fronted Goose, *Anser albifrons* (Scop.); the Mandarin Duck, *Aix galericulata* Linn.; the red-breasted Goose, *Branta sufficollis* Pallas; the Gadwall, *Chauleasmus strepera* Linn.; the Bewicks Swan, *Cygnus bewickii* Yarrel; the Whooper, *Cygnus cygnus* Linn.; the Mute Swan, *Cygnus olor* (Gmel.); the Pintail, *Dafila a. acuta* (Linn.); the Pond Heron, *Egretta a. alba* (Linn.); the Crested Teal, *Eunetta falcata* (Georgi); the Golden Eye, *Glaucionetta c. clangula* Linn.; the Wigeon, *Mareca penelope* (Linn.); the Smew, *Mergellus albellus* Linn.; the Goosander, *Mergus merganser merganser* Linn.; the red-breasted Merganser, *Mergus serrater* Linn.; the red-crested Pochard, *Netta rufina* (Pallas); the Common Teal, *Nettion c. crecca* (Linn.); the Formosan Teal, *Nettion formosum* (Georgi); the Scaup, *Nyroca m. marila* (Linn.); the Garganey Teal, *Querquedula querquedula* Linn.; the Shoveller, *Spatula clypeata* Linn.; and the Eastern Grey Plover, *Squatarola s. hypomela* (Palas).

My specimens were collected from the Common Teal, *Nettion c. crecca* (Linn.); 20.ii.1933; and the Dun Bird, *Nyroca f. ferina* (Linn.), 14.xi.1932 both shot in Lyallpur.

Measurements (mm.) of Trinoton querquedulae (Linn.).

	Female.		Male	
	Length.	Breadth.	Length.	Breadth.
Total	4.51	..	4.49	..
Head	0.74	1.09	0.75	1.17
Thorax	1.48	1.37	1.48	1.16
Abdomen	2.28	1.28	2.32	1.17
Head-index	1.608		1.56	

One specimen obtained from the Ruddy Sheldrake, *Casarca ferruginea* (Vroeg.), shot in Kulu, 21.x.1939, is placed temporarily in *T. querquedulae*, although it differs in some characters. However, it is apparent that it is closely related if not conspecific, but must await the examination of more material before it is identified with certainty.

Several immature specimens were also collected from the Himalayan Whistling Thrush, *Myophonus coeruleus temminckii* Vigors; shot in Kulu, 6.x.1939. It is certainly a straggler.

Piaget (1880) and Kellogg (1896) gave the measurements of female as 5.4 mm. \times 1.27 mm. and 5.0 mm. \times 1.56 mm., while of male as 4.7 mm. \times 1.0 mm. and 4.3 mm. \times 1.19 mm. respectively. According to the measurements given by them, the head-index of female and male calculated = 1.311, 1.6 and 1.222 and 1.428 respectively.

36. *Actornithophilus affine* (Nitzsch).

1818, *Colpocephalum affine*, Nitzsch, *Germ Mag.*, III, p. 299..

This species is one of the best known parasites recorded from various birds belonging to the sub-order LIMICOLA (CHARADRIIFORMES). Some of the hosts recorded from outside India are also found within our limits, viz. the Ringed Plover, *Charadrius hiaticula* (Linn.); the Oyster Catcher, *Haematopus ostralegus* Linn.; the Bar tailed Godwit, *Limosa lapponica lapponica* Linn.; the Lesser Tern, *Sterna minuta* Linn.; the Common Sandpiper, *Tringa hypoleucos* Linn.; the Green Sandpiper, *Tringa o. ochropus* Linn.; the Lapwing, *Vanellus vanellus* Linn.; etc.

My specimens, referred to below, were collected from the Black-winged Stilt, *H. h. himantopus* (Linn.); and the Green Sandpiper, *Tringa o. ochropus* Linn., 25.iv.1933 and 26.iv.1933 respectively, both shot in Lyallpur.

Measurements (mm.) of Actornithophilus affine (Nitzsch).

	Female.		Male.	
	Length.	Breadth.	Length.	Breadth.
Total	1.85	..	1.79	..
Head	0.35	0.51	0.34	0.43
Thorax	0.42	0.42	0.46	0.31
Abdomen	1.08	0.53	0.99	0.53
Head-index	1.457		1.264	

Piaget (1880) gave the measurements of female and male as 2.15 mm. \times 0.62 mm. and 1.8 mm. \times 0.47 mm. respectively, while the measurements of *C. ochraceum* (Piaget, 1880, a synonym of our species) are 2.15 mm. \times 0.62 mm., and 1.65 mm. \times 0.5 mm. respectively. According to the measurements given by this worker the head-index calculated = 1.333, 1.333, 1.351 and 1.393 respectively.

37. *Actornithophilus trilobatus* (Giebel).

1874, *Colpocephalum trilobatum*, Giebel, *Ins. Epiz.*, p. 278.

This species was first described from the Little Stint, *Erolia m. minuta* (Leis.). The specimens referred to below were collected from the type-host *Erolia m. minuta* (Leis.), 25.iv.1933, shot in Lyallpur.

Measurements (mm.) of Actornithophilus trilobatus (Giebel).

	Female.		Male.	
	Length.	Breadth.	Length.	Breadth.
Total	2.05	..	1.80	..
Head	0.35	0.53	0.32	0.41
Thorax	0.42	0.52	0.40	0.45
Abdomen	1.28	0.70	1.07	0.53
Head-index	1.514		1.281	

38. Austromenopon cursorius (Giebel).

1874, *Menopon cursorius*, Giebel, *Ins. Epiz.*, p. 296.

This species was first described from the specimens obtained from the Cream-coloured Courser, *Cursorius cursor cursor* (Lath.). The specimens referred to below were collected from the type-host shot in Lyallpur, 13.xii.1930.

Measurements (mm.): Length × Breadth.

Female: Total 1.75 × 0.83, head 0.21 × 0.68, thorax 0.41 × 0.50, abdomen 1.13 × 0.83, head-index 3.238.

Piaget's specimens measured $\frac{2}{3}$ ''' (1.69 mm.).

39. Austromenopon icterum (Nitzsch).

1838, *Menopon icterum*, Nitzsch, *Burmeisters' Handbuch der Ent.*, II, p. 44.

This species was originally described from the specimen taken off the Woodcock, *Scolopax r. rusticolor* Linn.; and since then has been recorded from various Limalicolae (Charadriiformes). My specimens were collected from the Black-winged Stilt, *Himantopus h. himantopus* (Linn.), 25.vi.1933; and the Green Sandpiper, *Tringa o. ochrophus* Linn., 26.iv.1933; both shot in Lyallpur. My specimens are very small and resemble those described and figured by Denny (1842).

Measurements (mm.) of Austromenopon icterum (Nitzsch).

7 Females.		5 Black-winged Stilt specimens.		2 Green Sandpiper specimens.	
		Length.	Breadth.	Length.	Breadth.
Total		1.273-1.294	.....	1.403-1.471	.....
Head		0.201-0.211	0.451-0.413	0.231	0.481-0.500
Pro-thorax		0.164-0.192	0.336-0.413	0.201-0.212	0.384
Ptero-thorax		0.101-0.135	0.413-0.423	0.115-0.154	0.432-0.442
Abdomen		0.769-0.794	0.558-0.577	0.817-0.913	0.644-0.673
Head-index		2.279-2.243		2.082-2.164	

Denny's specimens from the Sanderling, *Tringa variabilis*; measured $\frac{1}{2}$ ''' (1.27 mm.), while according to Piaget's measurements the female = 2.0 mm. × 0.79 mm., the head-index = 1.676.

40. *Myrsidea mesoleuca* (Nitzsch).

1818, *Menopon mesoleucum*, Nitzsch, in *German's Mag. Ent.*, III, p. 300.

It is a long known species of louse infesting crows, and has been recorded from all over the world. It was first described from *Corvus cornix* and *C. corone*, in Europe and since then has been taken off from other geographical races of Ravens, Hooded crows and Carrion crows.

It has also been recorded from various diurnal and nocturnal birds of prey, viz. the Buzzard, *Buteo lagopus*; the Falcon, *Falco communis*; the Peregrine Falcon, *Falco peregrinus* and *Sciurus vulgaris* (Germany: Mjöberg, 1910) and the Ural Wood Owl, *Strix uralensis fuscescens* (Japan: Uchida, 1926). The cause of such wide distribution of hosts may be attributed to straggling, either transmitted from game bag in which host-birds were carried or transmitted from a crow on which they might have preyed prior to having been shot.

The specimens referred to below were collected from the Eastern Rook, *Corvus frugilegus tshusii* (Hart.); the Punjab Raven, *Corvus corax laurencei* (Hume); and the Indian House Crow, *Corvus s. splendens* Vieill.

Measurements (mm.): Length × Breadth.

Female: Total 2.00 × 0.79, head 0.36 × 0.66, thorax 0.56 × 0.65, abdomen 1.08 × 0.79, head-index 1.833.

Piaget (1880) gave the measurements of male and female as 1.4 mm. × 0.56 mm. and 1.65 mm. × 0.66-0.80 mm. and according to his measurements the head-index calculated = 1.677 and 1.714 respectively.

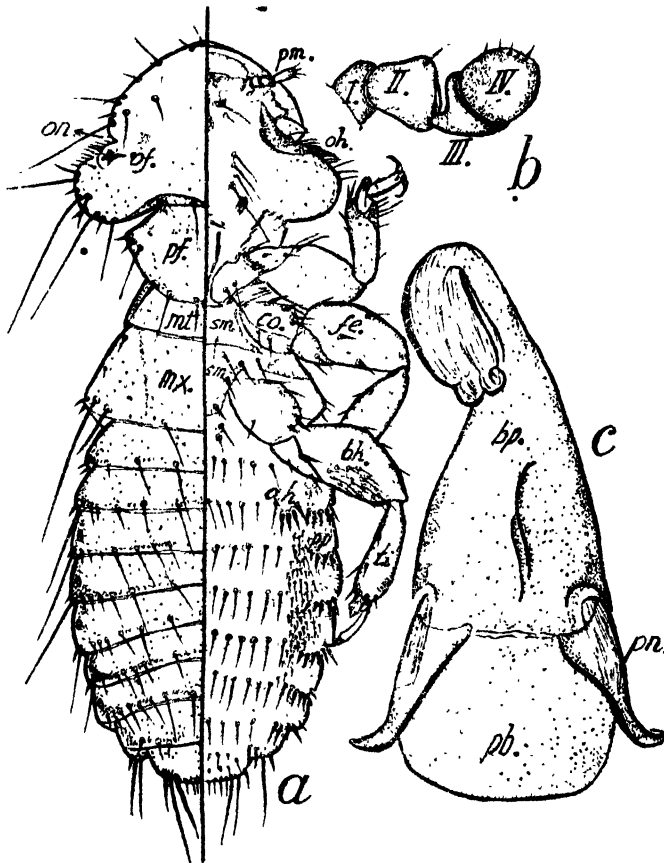
41. *Myrsidea flavirostratus* sp. nov.

Female (Text-fig. 18a): pale-brownish with dark-brown markings on head, and brown markings on thorax and abdomen.

Head concolorous with the body, occipital margin and curved line bounding antennal region pitchy-brown; slightly less broad than twice its length; front broadly parabolic, with a short hair and a minute spine on each side of the middle; two short hairs on the lateral margin, two long hairs in the lateral angles; two short hairs on the dorsum, one being near the lateral angle and the other in front of antennal blotch; eyes prominent with double cornea, ocular fleck black, cone-shaped, broader end three-lobed; temples expanded, broad; lateral margins rounded, each furnished with four long and 3-4 small marginal hairs and a short submarginal hair; anterior margin inferior to eyes, with a fringe of 9-11 backwardly curved stiff hairs; occipital margin slightly concave, edged with dark-brown chitin, bearing a minute spine and a fine hair on each half. Ventrum with quadrate gular plate, faintly chitinized, prominent, with three short and one long hair; oesophageal sclerite and glands present, small; antennal fossae with dark-brown anterior margin. Antennae (Text-fig. 18b) 4-jointed scape short; II joint dilated to one side, almost as broad as long; III joint oblique, calyciform, stalk short, immediately inserted on one side of segment II; IV joint squat sub-cylindrical, resting obliquely in shallow cavity behind, apical depression furnished with hairs.

Pro-thorax large, slightly less than twice as broad as long, much narrower than the head; lateral angles projecting, each with two spines and a spinous hair; posterior-lateral margins nearly straight, each with one long hair; posterior margin convex with two hairs on each half; transverse bar indistinct; lateral bars well developed, yellowish-brown. Meso-thorax distinct, short, lateral chitin clear pale, posterior margin nearly straight, bare. Meta-thorax large, produced posteriorly, lateral margins chitinized, diverging posteriorly, each bearing minute spines; posterior-lateral angles produced, furnished with three spines and a long hair; posterior

margin straight, one long hair and a small hair on each half. Legs paler than thorax, marginal markings on femora and tibia clear brown, narrow; posterior femora with about twenty-two minute ventral spinous hairs. Pro-sternal plate conical with two short hairs on the broad anterior margin; meso- and meta-sternum with well developed plates, bearing long hairs on the posterior margin; pericoxal plates well developed.



TEXT-FIG. 18. *Myrsidea flavirostratus*, sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), and (c) male genital armature (enlarged).

Abdomen elliptical, widest at the IV segment, latero-posterior angles projecting, each furnished with a long hair and 3-4 short spines; posterior margins concave, each furnished with a transverse row of hairs, of which outermost hairs become small and spinous; posterior margin of last segment truncate, beset with a short, marginal hair on each side of fine dorsal hairs and a fringe of weak hairs. Ventral surface of the abdominal segments with well developed sternal plates, each bearing a transverse row of spines; II sternite with 3-4 stiff, needle-like spines on latero-posterior angles, III-V sternites with a patch of closely set setae in each posterior angle; paracymbites well developed, bearing several short posterior setae.

Male: similar to female, smaller, II sternal plate with 2-4 needle-like spines at the latero-posterior angles; III-V sternites with no definite patch of setae. Genital armature (Text-fig. 18c) fairly chitinized, enlarged, apically articulating with thin

quadrate plate on either side of which are well built parameres with pointed and outwardly directed distal ends.

Measurements (mm.) of Myrsidea flavirostratus sp. nov.

	Female (Holotype).		Female (Paratype).		2 males.	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.756		1.681		1.23-1.38	.....
Head ..	0.311	0.612	0.339	0.582	0.28-0.29	0.49-0.51
Pro-thorax ..	0.213	0.372	0.213	0.372	0.14-0.18	0.31-0.35
Ptero-thorax ..	0.388	0.631	0.372	0.661	0.28-0.31	0.42
Abdomen ..	0.844	0.631	0.757	0.582	0.46-0.61	0.42-0.49
Head-index ..	1.967		1.717		1.717-1.834	

Holotype: A female from Kulu, 3.x.1939, on slide No. MA. 012H, *ex* the Yellow billed Magpie, *Urocissa f. flavirostris* (Blyth); *Allotype*: A male; *Paratype*: A female and two males (same data as above).

This species closely resembles *Myrsidea eury sternum* (Nitzsch) but is distinguished from it by considerably smaller size, shape of the body, parabolic front and general dorsal and ventral chaetotaxy. In *M. eury sternum* (Nitzsch) the abdomen of the female beyond segment III is drawn out into a long flat cone and the forehead is broadly rounded.

42. *Myrsidea brunnea* (Nitzsch).

1866 *Menopon brunneum*, Nitzsch, *Ziet. f. ges. Nat.*, XXVII, p. 120.

This species was first described from the Nutcracker, *Nucifraga caryocates* Linn. in Europe, and since then it has been recorded on the type-host from many parts of the world. The specimens referred to below were collected from the Himalayan Nutcracker, *Nucifraga carvocatectes hemispila* Vigors; shot in Lyallpur, 12.ii.1928, and Kulu (Kangra Valley), 14.x.1939.

Measurements (mm.) of Myrsidea brunnea (Nitzsch).

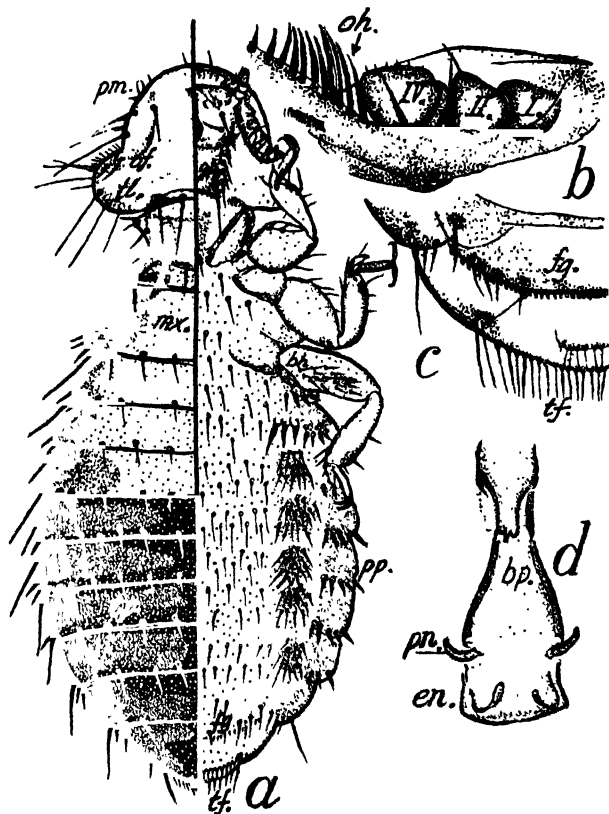
	Female.		Male.	
	Length.	Breadth.	Length.	Breadth.
Total	1.86	..	1.43	..
Head	0.36	0.59	0.28	0.40
Thorax	0.48	0.54	0.43	0.43
Abdomen	1.02	0.68	0.72	0.54
Head-index	1.639		1.42	

Piaget's (1880) male and female specimens measured 1.7 mm. × 0.56 mm. and 1.9-2.2 mm. × 0.6-0.75 mm. and accordingly the head-index calculated = 1.486 and 1.45 respectively.

43. *Myrsidea sehri*¹ sp. nov.

Female (Text-fig. 19a): body pale-brown, with dark-brown markings on head and thorax and brownish bands on abdomen.

Head broad, front rounded with a minute angulation on the meson, bearing a hair on each side of the angulation, a short hair on fronto-lateral margins; one long, two short and three to four minute hairs on a slight swelling of preocular area; a short hair on the dorsal surface; eyes large, flatly rounded; ocular fleck black, irregularly oblong with a short posterior seta; temples expanded, margins rounded, each with four very long, four short and a few minute hairs; ocular comb of short, stiff hairs present on the ventrally produced temporal margins; occipital margin slightly concave, edged with brown band, bearing four hairs; palpi projecting. Ventrums with well chitinized and highly pigmented sclerites; antennal fossae with dark-brown inner margin; antennae (Text-fig. 19b) 4-jointed, resemble that of *M. brunnea* (Nitzsch) in all essential characters and, therefore, call for no special description; oesophageal sclerite present, small and highly chitinized; posterior plate on the gular region distinct, quadrate, yellowish-brown, with four long and one exceptionally long hair; several short hairs scattered posterior to mandibles.



TEXT-FIG. 19. *Myrsidea sehri*, sp. nov.: (a) dorsal and ventral aspects of female, (b) ventral aspect of a portion of head showing antenna in repose (enlarged), (c) ventral aspect of the tip of abdomen, showing genital plate (enlarged), and (d) male genital armature (enlarged).

¹ *Sehri* is the vernacular name for the Simla Laughing Thrush.

Pro-thorax short; anterior portion deeply inserted under the occipital margin; lateral angles rectangular, each with two small spines; posterior lateral margins concave, with a short hair; posterior margin convex, bearing three hairs on each half; transverse bar distinct; lateral bars well chitinated. Meso-thorax narrow, lateral bands well chitinated, posterior margin almost straight. Meta-thorax trapezoidal, lateral margins almost straight, well chitinated, bare; posterior lateral angles produced, each with three spines, posterior margin nearly straight with one long and three short hairs on each half. Legs concolorous with the body; marginal markings on femora and tibia narrow, clear brown, bearing several short and minute hairs; hind femora with a group of 21 short, stiff hairs on its ventral surface, the inner ones being slightly longer, sternal plates well developed, of usual *Myrsidea* type and call for no special description.

Abdomen elliptical, widest at the IV segment; latero-posterior angles, each with a long hair and 2-3 spines; posterior margins of segments almost straight, each bearing a transverse row of 6-10 weak, short hairs, the lateral ones being slightly longer; last segment (Text-fig. 19c) broadly rounded with one minute, one long and one small hair; a fringe of fine, colourless hairs also present; transverse bands entire, lightly coloured in the middle, inter-segmental areas clear. Ventral surface of each abdominal segment bearing two rows of weak hairs; II sternite with three heavy spines on each side, III-VII sternites with a patch of closely set short hairs in lateral area; pleural plates well developed, bearing several short, heavy spines on posterior margin. Genital plate on IX sternite as shown in Text-fig. 19c.

Male: similar to female, smaller and narrower, especially abdomen which is more elliptical. Genitalia typical (Text-fig. 19d), paramere exceptionally reduced, short, strongly recurved; endomerai plate broad. A simple chitinous plate just before the expanded apex of the basal plate also present.

Measurements (mm.) of Myrsidea sehri sp. nov.

	Female (Holotype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.640	..	1.163	..
Head	0.311	0.475	0.291	0.388
Pro-thorax	0.145	0.311	0.116	0.252
Ptero-thorax	0.213	0.485	0.174	0.359
Abdomen	0.971	0.699	0.582	0.446
Head index	1.527		1.333	

Holotype: A female from Kulu, 6.x.1939, on slide No. MA. 015, ex the Simla Streaked Laughing Thrush, *Trochalopteron lineatum grisescentior* (Hart.); *Allotype*: A male (same data as above).

As far as I am aware this is the first *Myrsidea*, described from *Trochalopteron* species and is quite distinct from other forms which have so far been described or figured from Timaliidae.

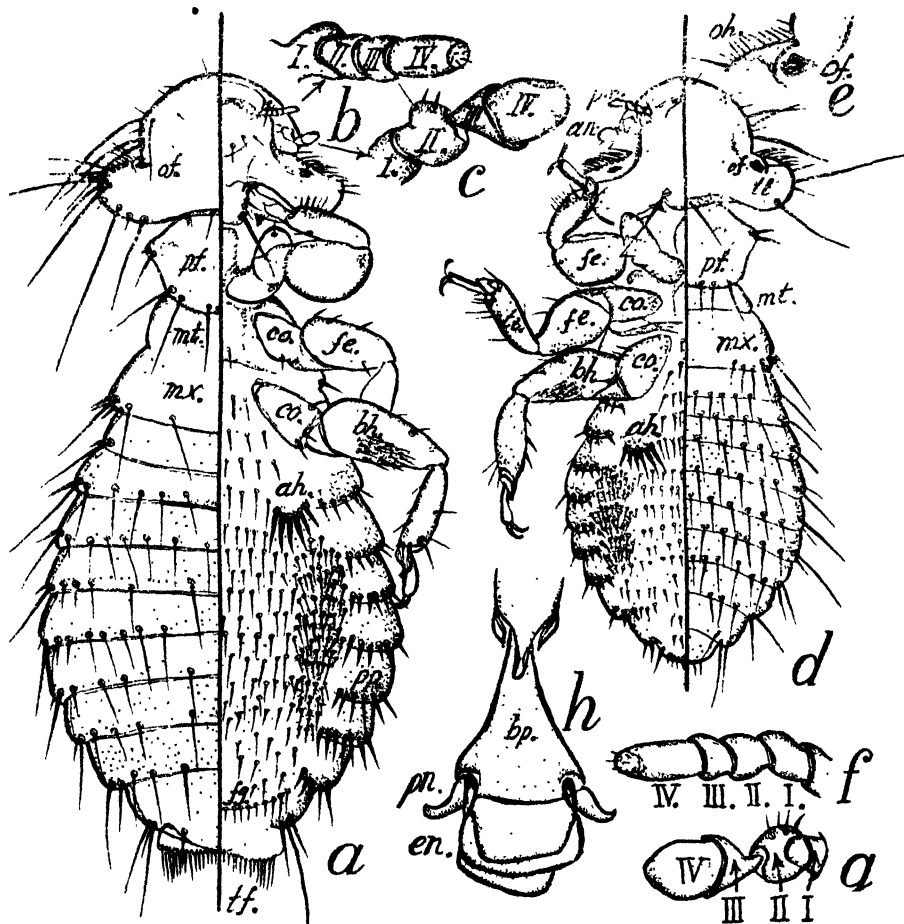
44. *Myrsidea satbhai*¹ sp. nov.

Female (Text-fig. 20a): body yellowish, with distinct brown markings on head and thorax, abdominal bands clear, pale-yellow.

Head broad, front broadly rounded; a minute hair on each side of the middle line, two short hairs near the anterior blotch, one such hair posterior to the blotch; two short and three long marginal and a long submarginal hair on the weak lateral

¹ *Sat-bhai* is the vernacular name for the 'Bengal Jungle Babbler'.

swellings; a minute hair on each side of the dorsum; lateral margins continuous with the eyes; eyes prominent, rounded; ocular fleck triangular, three-lobed; temples expanded, antero-laterally produced; ocular fringe composed of posteriorly curved stiff hairs, anterior ones being longest; four long, three short and several minute marginal hairs present; occipital margin flatly concave, ridged with narrow, weak, brown band, with one hair on each side of the middle line. On the ventral aspect of the head, chitinous framework for support of mandibles, pale-yellow, continued forwards to the anterior margin of the forehead; oesophageal sclerite present, small and simple; antennal fossae backed up by lightly chitinized area; antennae (Text-fig. 20c) projecting, 4-jointed; I joint simple and short; II joint irregularly pyriform, protruding on one side; III joint calyciform, driven in the preceding segment; IV joint cylindrical, subapical depression well marked; palpi (Text-fig. 20b) projecting, terminal joint longest, II-III joints small, subequal; gular plate small, with central perforation, chaetotaxy indistinct, four lateral hairs present, the posterior one being longest.



TEXT-FIG. 20. *Myrsidea satthai*, sp. nov.: (a) dorsal and ventral aspects of female, (b) maxillary palp of female (enlarged), (c) antenna of female (enlarged), (d) dorsal and ventral aspects of male, (e) ocular notch and eye (enlarged), (f) maxillary palp of male (enlarged), (g) antenna of male (enlarged), and (h) male genital armature (enlarged).

Pro-thorax short, hexagonal in outline, wings acute; lateral angles produced, rectangular, each with a spine and a short spinous hair; posterior lateral margins slightly concave, each with a long posterior hair; posterior margin convex bearing two long hairs on each side of a central pimple; transverse band yellow, distinct, lateral longitudinal bars brownish-yellow. Meso-thorax distinct; lateral margins brownish-yellow, slightly convex, bare; posterior margin straight, bare; Meta-thorax trapezoidal. Lateral margins brownish-yellow, narrow, slightly concave, diverging posteriorly, bare; posterior-lateral angles with one long hair and three short spines; posterior margin flatly convex, with two hairs on each half. Legs concolorous with the body, femoral and tibial markings narrow, brownish-yellow; hind femora with a thick ventral patch of short stiff hairs. Pro-sternum well developed, central plate, shaped like an inverted bottle, lateral bars highly chitinized; pro-coxal plates not touching each other in the middle, meso- and meta-sternal plates quadrate, furnished with fine hairs, peri-coxal bands well developed, yellowish-brown.

Abdomen elongate, elliptical, widest at V segment, each segment almost equal in length, latero-posterior angles projecting, each with a long hair and two spinous hairs, posterior margin of the first segment slightly convex, those of II-VIII gradually concave, each with a transverse row of fine hairs; last segment with a broadly rounded posterior margin, furnished with a group of three long marginal hairs, and one a short distance away towards the middle line; hyaline flap bearing fringe of closely set fine hairs between the marginal long hairs; transverse bands pale, entire; lateral bands yellow. Ventral aspect of IV-VII abdominal segments with distinct transverse blotches; each abdominal sternite with rows of short hairs; sternites IV-VII with definite lateral brushes of hairs, segment II beset with a cross of six heavy, needle-like spines on a flattened elevation; genital plate with a row of short hairs along posterior margin; pleural plates I-VIII, well developed, each with a posterior row of spines.

Male (Text-fig. 20*d*): similar to female, size smaller and slender; dorsum slightly more hairy, last segment posteriorly rounded, with several short marginal hairs. Genitalia (Text-fig. 20*h*) slender, basal plate moderately long, expanded at its apex, paramere very short, almost one-half as long as the endomeral plate, a complex chitinous structure near the apex of the basal plate, consisting of a broad plate, posteriorly produced into a tube on each side of which is a leaf-like structure.

Measurements (mm.) of Myrsidea satbhai sp. nov.

	Female (Holotype).		Female (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Body ..	1.656	..	1.656	..	1.662	..
Head ..	0.294	0.490	0.294	0.519	0.294	0.490
Pro-thorax	0.176	0.313	0.156	0.362	0.186	0.343
Ptero-thorax	0.255	0.509	0.245	0.539	0.235	0.441
Abdomen ..	0.931	0.686	0.961	0.735	0.647	0.588
Head-index	1.666		1.765		5.666	

Holotype: A female from Lyallpur, 16.iii.1932, on slide No. MA. 016, ex the Bengal Jungle Babbler, *Turdoides terricolor terricolor* Hodgs; ¹ *Allotype*: A male; *Paratype*: A female (same data as above).

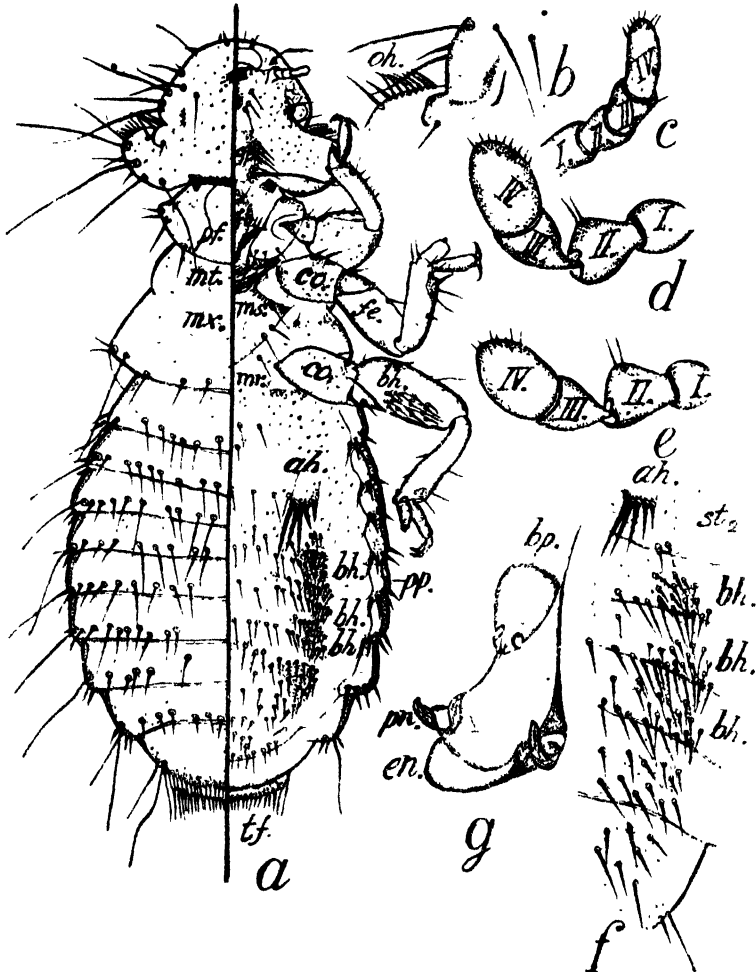
¹ It has been pointed out that Punjab form appears to be *Turdoides terricolor sindianus* Ticehurst. I retain the name *Turdoides terricolor terricolor* Hodgs on the authority of Bombay Natural History Society, who identified this specimen (*J. Bomb. Nat. Hist. Soc.*, XXXIX, p. 2).

This new species is allied to *Myrsidea dissimilis* (Kellogg) from the Purple Martin, *Progne subis*; and *Myrsidea subdissimilis* Uchida from the Japanese Blue-flycatcher, *Cyanoptila cyanomelana*; but differs from the former in smaller body and broader abdomen and from the latter in antero-laterally produced temples, dorsal and ventral chaetotaxy.

45. *Myrsidea chilchil*¹ sp. nov.

Female (Text-fig. 21a): body pale-brownish with distinct brown markings on head and thorax and brownish lateral bands on abdomen.

Head broad, front flatly rounded, truncate, slightly depressed in the middle; a short hair on each side of the middle, one short and a minute hair on the lateral blotch; sides slightly concave a short distance, then swollen and turned in at posterior



TEXT-FIG. 21. *Myrsidea chilchil*, sp. nov.: (a) dorsal and ventral aspects of female, (b) ocular notch and eye (enlarged), (c) maxillary palp of female (enlarged), (d) antenna of female (enlarged), (e) antenna of male (enlarged), (f) abdominal sternite showing chaetotaxy (enlarged), and (g) male genital armature (enlarged).

¹ *Chilchil* is the vernacular name for the Common Babbler.

angles to meet the eyes, each with four hairs of different sizes and one longest hair in the middle; dorsal surface with two long hairs, one being directed towards the outer margin; eyes distinct, hemispherical, with a minute posterior hair; temples broad, somewhat produced, rounded, a fringe of about twelve stiff, curving hairs along anterior margin; four long, two short and several minute hairs along lateral margins; posteriorly angular, meeting the slightly concave occipital margin, edged with narrow band, lateral blotches dark-brown, a long hair on each side of the middle line; palpi (Text-fig. 21c) projecting; antennal fossae chitinized on the internal margin, dark-brown; antennae (Text-fig. 21d) 4-jointed; I joint transverse, small, squat; II joint pear-shaped with its outer margin bulging to one side; II joint bell-shaped, pedunculate basally and regularly diverging towards the apex, basal stalk tucked in the apex of II joint, IV joint elongate, irregularly cylindrical, sub-apical groove wanting, apically furnished with minute hairs; gular plate distinct, quadrate, slightly more pigmented than the ground colour, with four short and one exceptionally long lateral hair; oesophageal sclerite and glands well developed, small.

Pro-thorax hexagonal in outline; lateral angles produced, each with two spines and a hair; posterior lateral margins concourse with the posterior margin, bare; posterior margin convex with one hair on each side; transverse bar indistinct; lateral band small, confined to the scapular region. Meso-thorax distinct, lateral margins edged with narrow bands, bare; posterior margin straight and bare. Meta-thorax trapezoidal, lateral margins almost straight, lateral band narrow, distinct, bare; latero-posterior angles, each with two spines and a long hair; posterior margin straight, each half with three hairs; legs concolorous with the body, marginal markings clear brown; posterior femora with a ventral patch of setae. Sternum as in the previous species (*Myrsidea satbhahi*, sp. nov.).

Abdomen broadly elliptical, widest at the IV segment; each segment almost equal in length; posterior angles projecting, each with a long hair and two spines; posterior margin of segments I-VIII slightly concave, those of segments IV-VII almost straight, segment VIII concave; each with a transverse row of short hairs; last segment broad, rounded, a long and a short hair on each side of a hyaline fringe of soft hairs; transverse bands indistinct, yellowish-brown; longitudinal sub-marginal bands present. Ventral aspect of each abdominal segment bearing a transverse row of short hairs on the posterior margin, IV-VIII segments with a median irregular transverse row; segments IV-VII with distinctly coloured transverse bands and a patch of roughly arranged short hairs, II sternite beset with five heavy, belonoid spines on a well formed callosity. Genital plate distinct, lying on the last segment, posterior margin dentate, bearing 16 short hairs. Pleural plates well formed, each with 3-4 posterior spines.

Male: agrees well with the female in all structures of the body and chaetotaxy. Genitalia (Text-fig. 21g) almost similar to *Myrsidea satbhahi*, sp. nov. (*vide supra*),

Measurements (mm.) of Myrsidea chilchil sp. nov.

	Female (Holotype).		Female (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.816	..	1.730	..	1.404	..
Head ..	0.356	0.509	0.346	0.500	0.298	0.461
Pro-thorax ..	0.182	0.336	0.192	0.346	0.192	0.317
Ptero-thorax ..	0.288	0.577	0.288	0.558	0.241	0.481
Abdomen ..	0.990	0.731	0.904	0.721	0.673	0.577
Head-index	1.429		1.446		1.547	

but the complex chitinous structure distinctly different; posterior tube reduced, with swollen tip, neatly placed in the anterior broad plate which is deeply emarginate with backwardly produced angles.

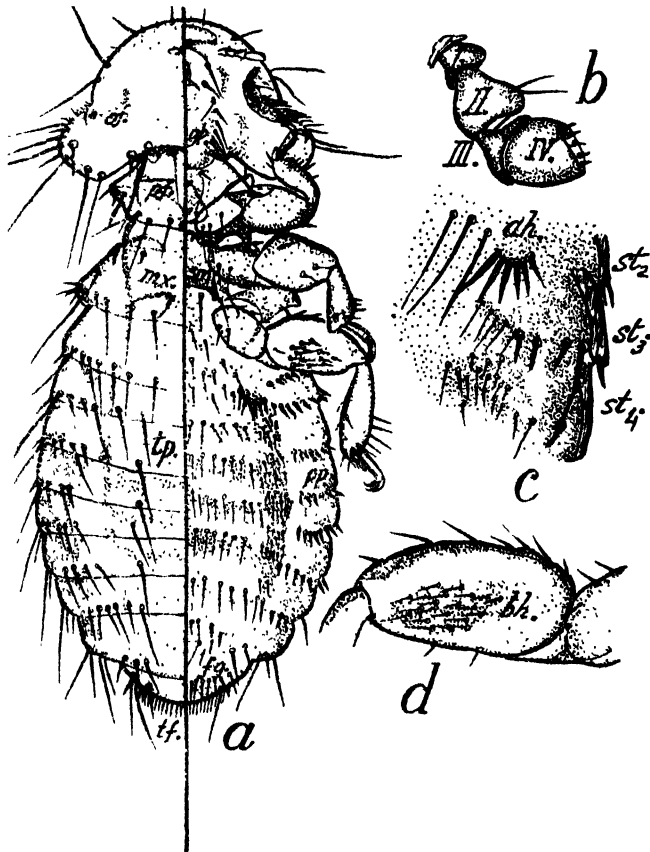
Holotype: A female from Lyallpur, 27.ii.1936, on slide No. MA. 017, ex the Common Babbler, *Argya c. caudata* (Dumont); *Allotype*: a male; *Paratype*: a female (same data as above).

This species closely resembles *Myrsidea satbhai*, sp. nov. (*vide supra*), but is distinguished from it by the shape of the head, ptero-thorax, asters of heavy spines, size of pleural plates, antennae and male genitalia.

46. *Myrsidea sultanpurensis* sp. nov.

Female (Text-fig. 22a): pale-brownish-yellow, with dark-brown markings on head and brown markings on thorax and abdomen.

Head broad, front rounded; sides swollen above the eyes, each with two long, two short and several minute hairs; eyes prominent, rounded with distinct irregularly rounded black fleck; palpus projecting; temples expanded, margins rounded, each bearing four very long, two slightly short and several very short marginal hairs; a short hair on the dorsal surface; occipital margin concave, edged with narrow, brown band, more pronounced on the lateral sides and fainter in the middle, bearing



TEXT-FIG. 22. *Myrsidea sultanpurensis*, sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) abdominal sternite showing chaetotaxy (enlarged), and (d) posterior femora showing ventral patch of hairs (enlarged).

one prickle, one long and one short hair on each half. Ventral aspect of the head with quadrate, posterior sclerite bearing five short and one long hair; three short hairs on the pharyngeal region; antennal fossa deep, dorsal flap complete, ventral flap reduced, bearing several curved hairs, crowded posteriorly and forming ocular fringe, inner margin chitinated, dark-brown. Antennae (Text-fig. 22b) 4-jointed, segments squat, shown in figure.

Pro-thorax hexagonal in outline, lateral angles produced, nearly rectangular, each bearing one spine, postero-lateral margin slightly concave, diverging posteriorly, each bearing one minute and one short spinous hair; posterior margin convex with three hairs on each side of a minute median ridge, transverse bar indistinct; longitudinal bars yellowish-brown. Meso-thorax distinct, pale-brown, bare; posterior margin straight, a minute marginal spine on each side. Meta-thorax trapezoidal, lateral margins pale-brown, chitinous band narrow, slightly concave anteriorly, diverging posteriorly, each bearing two minute spines; posterior lateral angles produced, each with three spines, posterior margin convex, bearing one long, one spinous and three short hairs on each side. Legs concolorous with the body, femora and tibia with distinct, spiny marginal bands; hind femora (Text-fig. 22d) with a distinct ventral patch of 21 short hairs. Sternal plates well developed, broad, bearing several long and minute hairs as shown in figure.

Abdomen broadly elliptical, widest at the IV segment, I segment slightly longer, others almost equal in length; posterior angles with 1-2 short spines; posterior margin of I and VIII segments strongly convex, posterior margin of II-IV segments slightly convex and those of the V-VII almost straight; dorsal surface of each segment with a transverse row of hairs on each side of the posterior margin of which some lateral ones becoming spinous; posterior margin of the last segment broadly rounded with two long and two short hairs on each side of a fringe of fine hairs; transverse bands brownish-yellow, entire on segments I-VIII, lateral bands brown. Ventral surface of I-VII abdominal segments with a transverse row of short hairs; II with an aster of six spinous hairs (Text-fig. 22c), III-VI segments with a patch of roughly arranged short hairs, segment VIII with numerous hairs confined in the middle. Pleural plates I-VIII well developed; I-VII plates with 6-8 short spines on the posterior margin, VIII plate with two long hairs and two spinous hairs; last segment with about 24 short hairs on the genital plate.

Male: not available.

Measurements (mm.) of Myrsidea sultanpurensis sp. nov.

3 females.			(Holotype).		(Paratype).	
			Length.	Breadth.	Length.	Breadth.
Total	..	..	1.669	..	1.572-1.619	....
Head	..	..	0.311	0.553	0.291-0.301	0.543-0.553
Pro-thorax	..	..	0.213	0.339	0.184-0.194	0.301-0.311
Ptero-thorax	..	..	0.223	0.543	0.165-0.223	0.495-0.524
Abdomen	..	..	0.922	0.776	0.922-0.932	0.699-0.776
Head-index	..	..	1.778		1.837-1.866	

Holotype: A female from Kulu, 6.x.1939, ex the Himalayan Whistling Thrush, *Myophonus coeruleus temminckii* Vigors; on slide No. MA. 022, *Paratype*: two females (same data as above).

This is the first record of any species of *Myrsidea* being collected and described from this bird. Though it has a somewhat superficial resemblance in general colour and outline to several *Colpocephalum* and *Menopon* species, collected from

various members of the sub-family Turdinae, yet it is readily recognized from all of them by the combination of different characters detailed above. *Myrsidea incertum* (Kellogg) is probably its nearest ally and differs from it in general chaetotaxy and in the size of the body.

47. *Myrsidea cucullaris* (Nitzsch).

1818, *Menopon cucullaris*, Nitzsch, *Germ. Mag.*, III, p. 300.

This species was first described from the Starling, *Sturnus vulgaris*, Linn.; in Europe, and since then has been recorded from various other Sturnidae from different parts of the world.

The specimens referred to below were collected from the Himalayan Starling, *Sturnus vulgaris himii* Brooks; from various parts of the Punjab.

Measurements (mm.): Length × Breadth.

Female: Total 1.50 × 0.58, head 0.28 × 0.46, thorax 0.43 × 0.48, abdomen 0.79 × 0.58, head-index 1.643.

Piaget (1880) gave the measurements of male and female as 1.2 mm. × 0.46 mm. and 1.5 mm. × 0.55 mm. respectively. According to his measurements the head-index of the two sexes is 1.466 and 1.393 respectively.

48. *Myrsidea lyallpurensis* sp. nov.

Female (Text-fig. 23a): body pale, brownish-yellow; with dark-brown markings on head, brown markings on thorax and brownish-pale on abdomen.

Head comparatively long, truncated front, sides almost straight, turned in at posterior angles to meet the eyes; frontal margin with two minute hairs on each side of the middle, two short hairs near the frontal blotch, two short and a long hair on the lateral margin and a long hair in the lateral angle, a short and a long hair on dorsal surface of the forehead, on each side of the dark-brown antennal blotch; eyes distinct, uniformly rounded; ocular fleck three-lobed, conical, transverse; temples moderately expanded, marginally rounded; bearing a fringe of 15 curved, stiff hairs along anterior margin, four long and several short marginal hairs; occipital margin shallow, edged with narrow band which is darker on tips and light in the middle, bearing two hairs. On the ventrum, mandibles are a short distance behind the frontal margin; labrum narrow with brownish lateral blotch; antennae and palpi slightly projecting beyond the margin; antennal fossae backed up with brown chitin; antennae (Text-fig. 23b) 4-jointed, resemble that of *Myrsidea brunnea*; quadrate, ventral sclerite pale, with four lateral hairs, posterior one being long; oesophageal sclerite and glands well developed, small.

Pro-thorax hexagonal in outline; lateral angles produced, rectangular each bearing two spinous hairs; postero-lateral margins slightly concave, each with two long hairs; posterior margin rounded with two hairs on both sides of a central papilla, transverse bar indistinct; longitudinal bars distinct, yellowish. Meso-thorax distinctly separated; lateral margin edged with pale-yellow chitin, bare; posterior margin almost straight, bare. Meta-thorax trapezoidal, lateral margins slightly concave or almost straight, diverging posteriorly, edged with very narrow hyaline, yellow band, bare; posterior lateral angle blunt, produced, each with several spines and a long hair; posterior margin straight, bearings six or seven short hairs. Legs paler than the body, with clear marginal markings on femora and tibia; ventral surface of posterior femora with a group of thirty-two short stiff hairs (Text-fig. 23c) the inner row being of longer hairs while outer row of shorter hairs. Sternal plates

Male (Text-fig. 23d): similar to female, but smaller, last segment truncate, fringe of hairs wanting. Genital armature (Text-fig. 23f) as in *Myrsidea chilchil*, sp. nov. described above but there the parameres are narrow and long.

Measurements (mm.) of Myrsidea lyallpurensis sp. nov.

	Female (Holotype).		Female (Paratype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.	Length.	Breadth.
Total ..	1.532	..	1.421	..	1.251	..
Head ..	0.311	0.474	0.288	0.422	0.274	0.429
Pro-thorax ..	0.170	0.311	0.148	0.281	0.185	0.259
Ptero-thorax ..	0.296	0.466	0.237	0.444	0.200	0.348
Abdomen ..	0.755	0.644	0.748	0.600	0.592	0.451
Head-index ..	1.524		1.465		1.565	

Holotype: A female from Lyallpur, 16.vi.1931, on slide No. MA. 031, ex the Common Indian Myna, *Acridotheres t. tristis* (Linn.); *Allotype*: a male; *Paratype*: a female (same data as above).

It resembles *Myrsidea invadens* (Kell. & Chap), described from *Acridotheres t. tristis*; but differs from it in smaller body, shape of the head, in longer ptero-thorax, in ovate abdomen, and in general chaetotaxy. These specimens are decidedly more hairy.

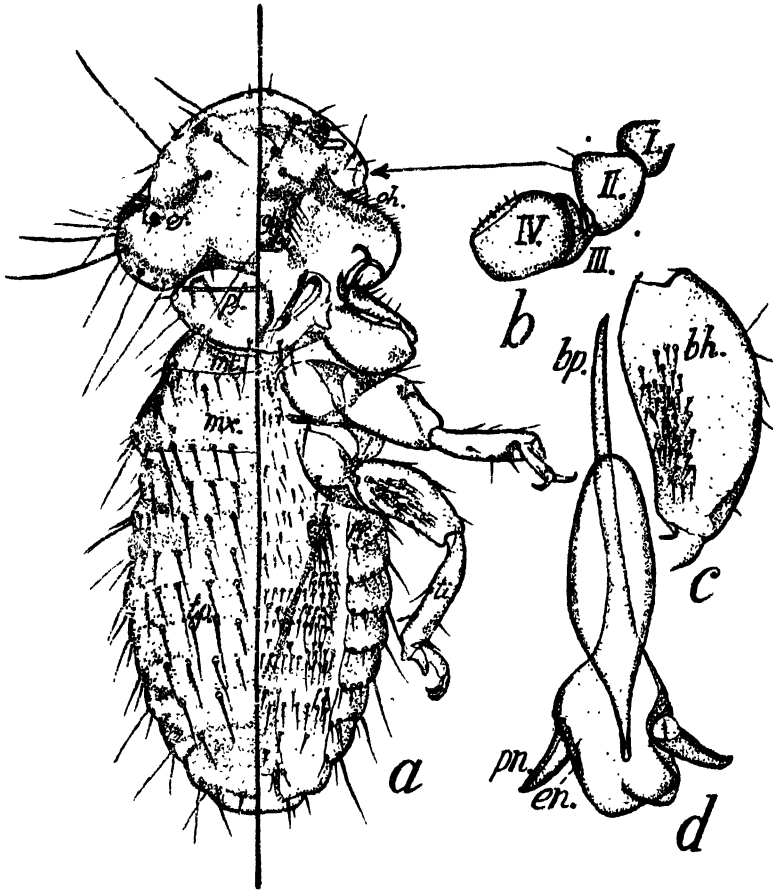
49. *Myrsidea dukhunensis* sp. nov.

Male (Text-fig. 24a): body pale-brownish with dark-brown markings and bands on head and thorax, and brown markings on abdomen.

Head broad, front rounded; a minute hair on each side of the middle line, one slightly longer and one minute hair in front of anterior blotch; lateral margins in front of eyes swollen, bearing two long, one short and a minute hair; two hairs on each side of the dorsum of forehead; eyes small, prominently emarginated in the middle; ocular fleck irregularly quadrangular with a posterior short hair, temples swollen, expanded, margins posteriorly rounded; temporal bands deep brown, furnished with four long, four short and an ocular comb of stiff, curved hairs continued on the ventral extension; occipital margin concave, edged with dark-brown chitinous band, which narrows outwardly, faintly pigmented in the middle, a long hair and a prickle on both sides of the middle line. Ventrum with strongly chitinized framework which continues as far as the outer margin of the forehead, thence running downwards and backwards along the antennal fossae, and a well chitinized broad band connecting the right and the left, continued posteriorly to the quadrate ventral sclerite on the gular region which bears five short and a long hair on each side; oesophageal sclerite and glands well developed; antennal fossae with dorsal flap, entire and ventral flap reduced to a ridge; antennae 4-jointed (Text-fig. 24b) resembling *Myrsidea brunnea* (Nitzsch) but slightly modified as shown in figure.

Pro-thorax large, inserted below the occipital margin; lateral angles obtuse each bearing two spines; lateral margins practically confluent with the posterior margin, strongly converging; posterior-lateral margins convex, each bearing a small hair; posterior margin with a short, central spindle-shaped ridge, three small hairs on each side; transverse bar well developed, yellowish-brown; longitudinal bars deep-brown, broad anteriorly and tapering posteriorly; posterior chitinous band well developed. Meso-thorax distinct, narrow; lateral margins straight, chitinous lateral bands dark-brown; a short hair in the lateral-posterior angle; posterior

margin straight with a transverse row of short hairs. Meta-thorax trapezoidal; lateral margins chitinized, dark-brown, slightly concave, with two spines; posterior-lateral angles produced, each bearing two spines and a long hair; posterior margin almost straight with six hairs on each side; legs concolorous with the body; marginal bands on femora and tibia dark-brown, bearing numerous hairs; hind femora with a patch of numerous short hairs (Text-fig. 24c), sternal plates and pericoxal bars well developed.



TEXT-FIG. 24. *Myrsidea dukhunensis*, sp. nov.: (a) dorsal and ventral aspects of male, (b) antenna of male (enlarged), (c) ventral aspect of posterior femora (enlarged), and (d) male genital armature (enlarged).

Abdomen elongate, elliptical; widest at IV segment; posterior angles with two long hairs and 1-2 short spines; length of segments I-VIII almost equal, segment IX broader and segment X shortest; I-VI segments with a single transverse row of hairs on the posterior margin, VII segment with two hairs on each side, VIII segment with only one hair, IX segment with three long hairs in the posterior angles and a short hair on the posterior margin; last segment flatly rounded, bare; transverse tergal bands brownish-yellow with fainter inter-segmental spaces, entire on I-IX segments; last segment with a dark-brown band on the posterior margin; ventral aspect of each segment bearing two transverse rows of short hairs; II segment with asters of three heavy spines on each side of the sternite; III-VI

segments with a patch of short hairs; pleural plates I–VIII well developed; each with a posterior row of spines. Genitalia (Text-fig. 24d) composed of an exceedingly long basal plate, slender anteriorly, broad posteriorly; parameres short and broad with pointed distal ends; endomeres faintly chitinized; median ventral structure tubular, produced posteriorly and reaching as far as the middle of preputial sac.

Female: not available.

Measurements (mm.) : Length \times Breadth.

Holotype (male): Total 1.518×0.567 , head 0.356×0.577 , pro-thorax 0.182×0.365 , ptero-thorax 0.211×0.500 , abdomen 0.769×0.567 , head-index 1.576.

Holotype: A male from Kulu, 3.x.1939, ex the Indian White Wag-tail, *Motacilla alba dukhunensis* (Sykes), on slide No. MA. 036.

The present species can be distinguished from other species of the genus by difference in size, general chaetotaxy, and head which is broader than the body, and aster on each side of the II abdominal sternite.

50. *Myrsidea* sp.

Two immature specimens were collected from the Red-billed Blue Magpie, *Urocissa erythrorhyncha occipitalis* (Blyth); shot in Lyallpur, 10.ix.1928.

51. *Myrsidea* sp.

One immature specimen was taken off the Eastern Indian Red Start, *Phoenicurus ochruros rufiventris* (Vieill.); shot in Kulu (Kangra district), 3.x.1939.

ALCEDINIPHILUS subgen. nov.

Body medium sized, fairly chitinized; with well defined tergal, paratergal and sternal plates.

Head broad, front rounded with slightly swollen lateral margins, ocular emargination distinct; temples expanded, rounded marginally; framework for support of mandibles, weakly chitinized, antennae 4-jointed; oesophageal sclerites small, modified.

Pro-thorax short, broad; meso- and meta-thoraces distinctly separated; legs normal, hind femora with a distinct patch of stiff hairs on the ventrum.

Abdomen elongate; transverse incassations well formed, each with a transverse row of weak hairs on the lateral one third; sternal plates bearing transverse row of hairs, and indistinct patches of several short and weak hairs on each side merging with general chaetotaxy, II abdominal sternite with aster of stiff hairs. Last segment exhibiting sexual dimorphism, posterior margin with a mesal emargination and fringe of fine hairs in female, and rounded in male.

Genital armature entirely different from other *Myrsidea*, well built, basal plate long and slender, reaching the posterior margin of III abdominal segment, tapering anteriorly and distended posteriorly; parameres short and stout, apically recurved; endomerall plate broad, outer lateral margins faintly chitinized, posterior margin broadly rounded, complex structure near apex of the plate wanting.

This subgenus differs from *Myrsidea* Waterston, s. str. in that (i) ocular emargination distinct, (ii) meso- and meta-thoraces completely fused, short, trapezoidal, (iii) hind femora with distinct patches of stiff hairs, (iv) last segment in female bifid furnished with a fringe of fine hairs, and (v) genital armature without central complex structure. The possession of these characters probably does not warrant erection of new genus, in view of many similarities, therefore it is best if kept as subgenus of *Myrsidea* Waterston.

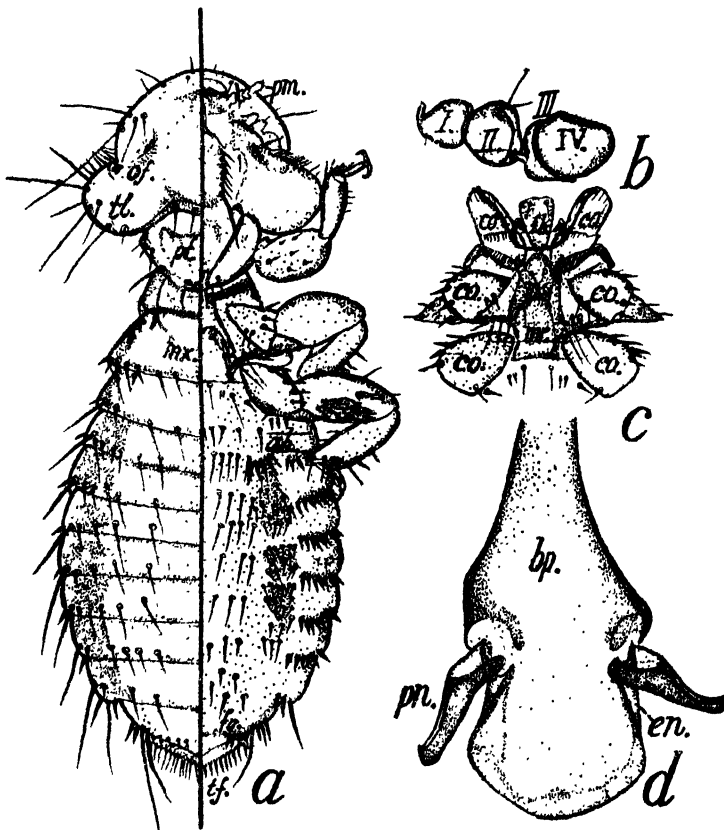
Occurring on Kingfishers (Alcedinidae).

Type of the subgenus: *Myrsidea (Alcediniphilus) kuluensis* sp. nov. (*vide infra*) ex the Himalayan Great Pied Kingfisher, *Ceryle lugubris guttulata* Stej.

52. *Myrsidea (Alcediniphilus) kuluensis* sp. nov.

Female (Text-fig. 25a): body pale-brownish with dark-brown markings on head and brownish markings on thorax and abdomen.

Head broad, front rounded with slight notch on the meson; a very minute hair on each side of the notch; one short hair and a minute hair on the lateral margin; two long and two minute hairs on sides, swollen above the base of shallow but distinct ocular emargination; two subequal hairs on the dorsal surface of the head; eyes present, rounded, single cornea, with pear-shaped fleck bearing a short posterior seta; temples expanded, margins rounded, each bearing three long, four short and seven minute hairs, fringe of several stiff curved hairs on the margin, just below the eyes and continued on to the ventral flap of antennal fossa; occipital margin strongly concave, edged with dark-brown band, bearing four hairs; occipital blotch present; ventrum with weakly chitinized framework; gular plate quadrate, bearing five lateral hairs, posterior one being longest; antennal cavity shallow, dorsal flap complete, ventral continuation of temporal lobes narrow, inner border



TEXT-FIG. 25. *Myrsidea (Alcediniphilus) kuluensis*, sp. nov.: (a) dorsal and ventral aspects of female, (b) antenna of female (enlarged), (c) thoracic ventral plates (enlarged), and (d) male genital armature (enlarged).

of the fossae highly chitinated, dark-brown; antennae 4-jointed (Text-fig. 25b), segments squat and reduced, similar to *Myrsidea dukhunensis* sp. nov. (*vide supra*), slightly modified, as shown in figure; oesophageal sclerite modified, not well chitinated.

Pro-thorax short and broad; lateral angles rectangular, each with very small spines; posterior lateral margins slightly concave, bearing a small anterior spine; posterior margin convex with three short hairs on both sides of a small central pimple; transverse bar distinct, lateral bands well chitinated. Meso-thorax distinct; lateral margins slightly projecting, almost straight; posterior margin nearly convex, bearing two minute hairs. Meta-thorax trapezoidal; lateral margins straight, diverging posteriorly, edged with chitinous bands, furnished with two spines; postero-lateral angles produced, each with two spines; posterior margin slightly convex, bearing one long, one spinous and three short hairs. Legs slightly paler than the body with narrow, clear brown marginal chitin on femora and tibia; posterior femora with 21 stiff hairs on the ventrum, out of which eighteen furnishing a patch, while three are solitary. Pro-sternal plate well built, as shown in figure, meso- and meta-sternum separated.

Abdomen elongate, elliptical, widest at V segment; posterior angles projecting, each with a long hair and a spine; length of the segments II-VIII almost equal, segments I and IX longest; posterior margins convex, each furnished with a transverse row of weak hairs, confined on the lateral one-third; posterior margin of last segment with a mesal angulation, bearing one long and several small and minute hairs, a fringe of fine hairs on the ventral hyaline flap; transverse bands yellowish-brown, entire across each segment, lateral bands clear brown. Ventral surface of each abdominal sternite bearing a transverse row of hairs and several short and weak hairs on each side merging more or less with general chaetotaxy; II sternite with five stiff spines, set on a callosity; pleural plates I-VIII well built, each bearing several spines on posterior margin; posterior lateral margin of segment IX with 2-3 spinous hairs and a long hair; posterior margin with four short hairs, a fringe of fine hairs between long hairs.

Male: similar to female, but smaller, abdomen narrow; last segment rounded without angulation. Genitalia (Text-fig. 25d) well built, reaching from the posterior margin of III abdominal segment to the posterior end of last segment; basal plate slender tapering anteriorly and broadly expanded posteriorly; parameres short and stout, apically recurved; endomeral plate broad, outer lateral margins faintly chitinated, posterior margin broadly rounded.

Measurements (mm.) of Myrsidea (Alcediniphilus) kuluensis sp. nov.

	Female (Holotype).		Male (Allotype).	
	Length.	Breadth.	Length.	Breadth.
Total	1.630	..	1.358	..
Head	0.339	0.592	0.291	0.534
Pro-thorax	0.194	0.339	0.194	0.324
Ptero-thorax	0.204	0.524	0.194	0.485
Abdomen	0.893	0.757	0.679	0.582
Head-index	1.746		1.834	

Holotype: A female from Kulu, 4.x.1939, ex the Himalayan Great Pied Kingfisher, *Ceryle lugubris guttulata* Stejneger, on slide No. MA. 040H; *Allotype*: a male (same data as above).

This species resembles *Colpocephalum pustulosum* Piaget from *Ceryle pugnax* and *C. subpustulatum* Carr. & Shull from *Ceryle alcyon*. From the former, it can be distinguished by the absence of conspicuous double row of clear pustules on the abdomen and head, shape of forehead, temples and pro-thorax, while from the latter it differs in the presence of the fringe of fine hairs on the posterior extremity of the abdomen and general chaetotaxy.

53. *Laemobothrion tinnunculi* (Linn.).

1758, *Pediculus tinnunculi*, Linnaeus, *Syst. Nat.*, p. 612.

This species has been recorded from various birds belonging to the family Falconiformes. The following of its avian-hosts, viz. the Marsh Harrier, *Circus aeruginosus* Linn.; the European Griffon, *Gyps f. fulvus* Hab., and the Hobby, *Falco subbuteo* Linn. are also common within Indian limits.

One immature specimen was taken off the Lagger Falcon, *Falco jugger* Gray; shot in Lyallpur, 5.i.1929.

54. *Laemobothrion titan* (Piaget).

1880, *Laemobothrium titan*, Piaget, *Les Pediculines*, p. 578, pl. 49, fig. 1.

This species was first described from the Black Kite, *Milvus migrans* (Bodd.) and since then has been recorded from various other diurnal birds of prey. Most of these Accipitrines occur within Indian limits, viz. the Sleppe or Desert Buzzard, *Buteo vulpinus* (Gloger); the European Kestrel, *Cerchneis t. tinnunculus* (Linn.); the Black-chested Harrier Eagle: *Circaetus pectoralis*; the Cape Vulture, *Gyps caprotheres*; the Black-eared Kite, *Milvus migrans lineatus* Gray; the Black Kite, *Milvus migrans migrans* (Bodd.); and the Osprey, *Pandion h. haliaetus*. Kellogg and Paine (1914) recorded it from the Blyth Baza, *Baza j. jerdoni* (Blyth) in Eastern Himalayas.

Several adult and immature specimens (Text-fig. 26a-d) referred to below were collected from the Common Pariah Kite, *Milvus migrans govinda* Sykes; shot in Lyallpur, 5.iv.1933.

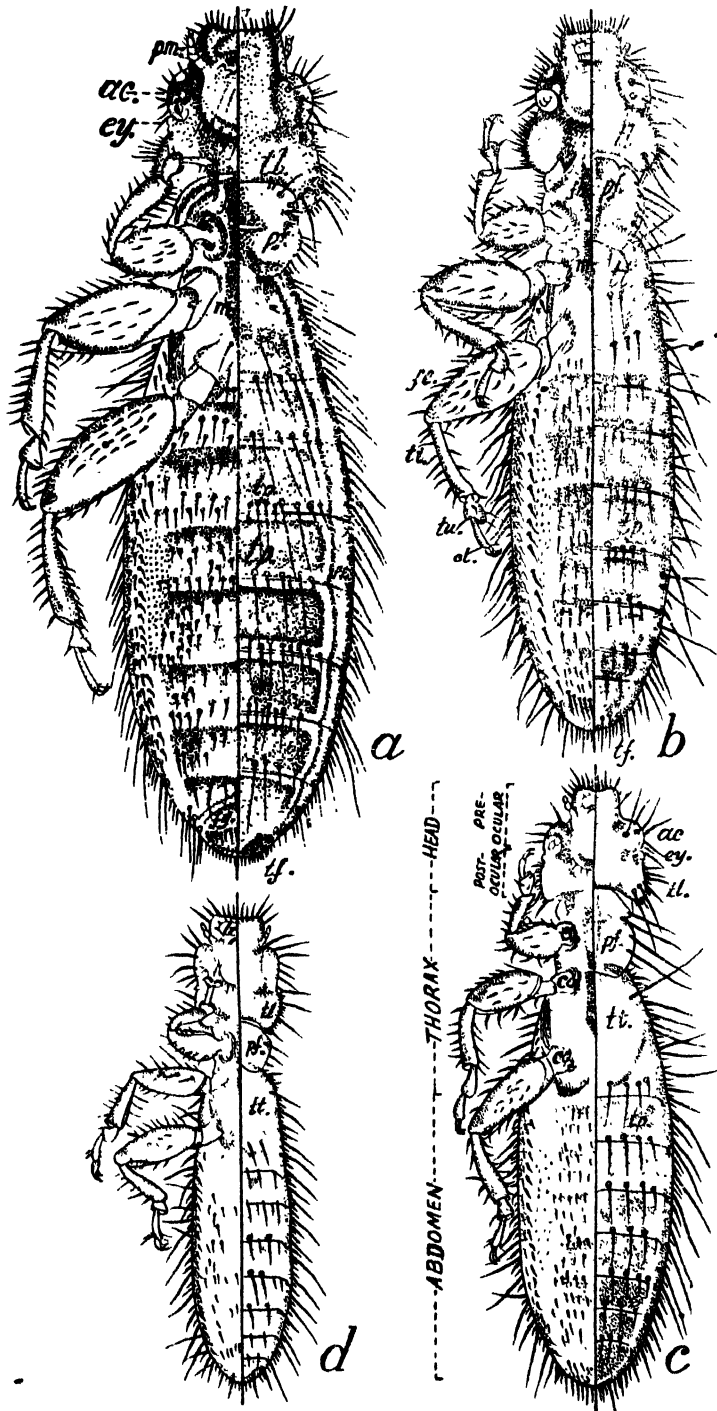
Measurements (mm.) : Length × Breadth.

20 Females: Total 8.50-9.50 × 2.30-2.50, head 1.53-1.56 × 1.55-1.60, thorax 2.06-2.21 × 1.07-1.97, abdomen 4.60-5.49 × 2.30-2.50, head-index 1-1.045.

Piaget (1880) gave the measurements of his female specimens as 10.4 mm. × 2.5 mm. From the text measurements, the head-index is calculated at 0.967. *Laemobothrion gypsis* (Kellogg, 1906), one of its synonyms, measured 11.0 mm. in length. Sen (1942) recently described *Laemobothrion indica* from specimens taken off the Common Pariah Kite, *Milvus migrans govinda* Sykes. His female specimens, however, measured 8.5 mm. × 2.1 mm. It was not possible for me to examine his material, but the description and figure indicates that it is similar to *L. titan*. The head-index (calculated = 1.143) is also within the range of that calculated for specimens of *L. titan* Piaget (1880) collected by me from this host. I consider, therefore, that *L. indica* Sen is a synonym of *L. titan* Piaget.

55. *Laemobothrion* sp.

Several immature specimens were collected from the Himalayan Griffon Vulture, *Gyps himalayensis* Hume; shot in Lyallpur, 9.i.1930. I did not get an opportunity to examine specimens of *Laemobothrion* from the type-hosts of the species described from Aegypiidae, therefore it has been considered advisable to leave the exact determination until more material, especially adults, is available to me for study.



TEXT-FIG. 26. *Laemobothrion titan* Piaget: dorsal and ventral aspects of (a) adult female and (b, c and d) III, II and I stage nymphs.

III. SUMMARY.

An account of fifty-five species of Amblyceron Mallophaga, belonging to twenty genera, is given. This includes the description and figures of five new genera and subgenera, viz. *Columbimenopon*, *Galliferrisia*, *Ululoeus*, *Picophilus* and *Alcediniphilus* and twenty-five new species, viz. *Columbimenopon modestus* ex the Indian Ring Dove—*Streptopelia d. decaocta* (Frival.), *Columbimenopon chanabensis* ex (?) the Himalayan Griffon Vulture—*Gyps himalayensis* Hume, *Uchida abdominalis indicus* ex the Common Grey Quail—*Conturnix c. conturnix* (Linn.), *Uchida kalatitar* ex the Indian Black Partridge—*Francolinus f. asiaticus* Bonap., *Menacanthus guldum* ex the Punjab Red-vented Bulbul—*Molpastes cafer intermedius* (Jerdon), *Menacanthus safedgal* ex the White-cheeked Bulbul—*Molpastes l. leucogenys* (Gray), *Menacanthus dudiyalatora* ex the Indian Great Grey Shrike—*Lanius excubitor lahtora* (Sykes), *Menacanthus gulabimaina* ex the Rosy Starling—*Pastor roseus* (Linn.), *Menacanthus himalayicus* ex the Himalayan Starling—*Sturnus vulgaris humii* Brooks, *Galliferrisia tuusi* ex the Common Indian Pea-fowl—*Pavo cristatus* Linn., *Pseudocolpocephalum doriabagla* ex the Indian Cattle Egrot—*Bubulcus ibis coromandus* (Bodd.), *Cuculiphilus upak* ex the Common Hawk Cuckoo—*Hierocoryx varius* Vahl., *Cuculiphilus pupiya* ex the Indian Pied Crested Cuckoo—*Clamator j. jacobinus* (Bodd.), *Cuculiphilus* (*Ululoeus*) *panjabensis* ex the Northern Spotted-Owlet—*Athene brama indica* (Frankl.), *Cuculiphilus* (*Picus-philus*) *tirkhan* ex the Himalayan Scaly-bellied Green Wood-pecker—*Picus s. squamatus* Vigors, *Menopon interpositus* ex the Northern Grey Partridge—*Francolinus pondicciarius interpositus* Hart., *Neomenopon baktitar* ex the Indian Common Sandgrouse—*Pterocles exustus erlangeri* Neum., *Myrsidea flavirostratus* ex the Yellow-billed Magpie—*Urocissa f. flavirostris* (Blyth.), *Myrsidea schri* ex the Simla Stroaked Laughing Thrush—*Trochalopteron lineatum griseiventris* (Hart.), *Myrsidea sathhai* ex the Bengal Jungle Babbler—*Turdoides terricolor terricolor* Hodgs, *Myrsidea chilchil* ex the Indian Common Babbler—*Argya c. caudata* (Dumont), *Myrsidea sultanpurensis* ex the Himalayan Whistling Thrush—*Myophonus coeruleus temminckii* Vigors, *Myrsidea tyallpurensis* ex the Common Indian Myna—*Acridotheres t. tristis* (Linn.), *Myrsidea dukhunensis* ex the Indian White Wag-tail—*Motacilla alba dukhunensis* (Sykes) and *Myrsidea* (*Alcediniphilus*) *kuluensis* ex the Himalayan Great Pied Kingfisher—*Ceryle lugubris guttulata* Stejneger. About forty-three species are recorded here for the first time from the Punjab.

A few of the recorded species differ from the description and figures of previous workers in certain morphological details and size and seem well differentiated to warrant their being treated as varieties, or even as subspecies or species, but as the type specimens were not available to me, no attempt has been made to alter their existing status.

IV. ADDENDUM.

After the type-script of this paper was sent to the press, Miss Theresa Clay of the British Museum (Natural History), London, directed my attention to a paper recently published by Eichler in *Arkiv for Zoologi* (1947 : 39A(2), p. 10) in which the author describes a new genus for *Colpocephalum appendiculatum* Nitzsch from *Argus argus* and calls *Galligogus*. She further adds that there seems no doubt that it is congeneric with *Galliferrisia* (gen. nov.) from *Pavo cristatus* Linn. (*vide supra*), the description of which was sent, sometime back, to her for opinion. It was not possible for me to see this important publication and I am indebted to Miss Clay for calling my attention to it.

V. A LIST OF MALLOPHAGAN PARASITES WITH BIRD-HOSTS.

- Actornithophilus affinis* (Nitzsch) from the Black-winged Stilt (*Himantopus h. himantopus* (Linn.): Charadriidae) and the Green Sand-piper (*Tringa o. ochrophus* Linn.: Scolopacidae).
A. trilobatus (Giebel) from the Little Stint (*Erolia m. minuta* (Linn.): Scolopacidae).
Alcolpocephalum subaequale (Nitzsch) from the Panjab Raven (*Corvus corax laurencei* Hume: Corvidae) and the Common Indian House Crow (*Corvus s. splendens* Vieill.: Corvidae).
Ardeiphilus trochurus (Nitzsch) from the Indian Pond Heron (*Ardeola grayii* (Sykes): Ardeidae).
Austromenopon cursorius (Giebel) from the Cream-coloured Cursor (*Cursorius cursor cursor* (Lath.): Glareolidae).
Austromenopon icterum (Nitzsch) from the Black-winged Stilt (*Himantopus h. himantopus* (Linn.): Charadriidae) and the Green Sandpiper (*Tringa o. ochrophus* Linn.: Scolopacidae).
Colpocephalum tricinatum Nitzsch from the Common Pariah Kite (*Milvus migrans govinda* Sykes: Falconidae).
Colpocephalum sp. from the Himalayan Griffon Vulture (*Gyps himalayensis* Hume: Aegypiidae), and the Lager Falcon (*Falco jugger* Gray: Falconidae).
Columbimenopon chanabensis sp. nov. from the Himalayan Griffon Vulture (*Gyps himalayensis* Hume: Aegypiidae)—? Straggler.
Columbimenopon modestus sp. nov. from the Indian Ring Dove (*Streptopelia d. decaocta* (Frival.): Columbidae).

- Columbimenespon* sp. from the Indian Blue Rock Pigeon (*Columba livia intermedia* Strick: Columbidae).
- Cuculiphilus upak* sp. nov. from the Common Hawk Cuckoo (*Hierococcyx varius* Vahl.: Cuculidae).
- C. pupiya* sp. nov. from the Indian Pied Crested Cuckoo (*Clamator j. jacobinus* (Bodd.): Cuculidae).
- Cuculiphilus (Picusphilus) tirkhan* sp. nov. from the Himalayan Scaly-bellied Green Wood-pecker (*Picus s. squamatus* Vigors: Picidae).
- Cuculiphilus (Ululoeus) panjabensis* sp. nov. from the Northern Spotted Owlet (*Athene brama indica* (Frankl.): Asionidae).
- Cuculiphilus (Ululoeus)* sp. from the Indian Barn Owl (*Tyto alba stretens* Hart.: Tytonidae) and the Great Horned Owl (*Bubo bubo bengalensis* (Frankl.): Asionidae).
- Eomenacanthus stramineus* (Nitzsch) from the Common House Hen (*Gallus g. domesticus* Linn.: Phasianidae).
- Galliferrisia tarsi* sp. nov. from the Common Pea-fowl (*Pavo c. cristatus* Linn.: Phasianidae).
- Laenobothrion tinnunculi* (Linn.) from the Lesser Falcon (*Falco jugger* Grey: Falconidae).
- L. titan* (Piaget) from the Common Pariah Kite (*Milvus migrans govinia* Sykes: Falconidae).
- Laenobothrion* sp. from the Himalayan Griffon Vulture (*Gyps himalayensis* Hume: Falconidae).
- Menacanthus dubiigalatora*, sp. nov. from the Indian Great Grey Shrike (*Lanius excubitor lahtori* (Sykes): Laniidae).
- M. gonophoeus* (Burmeister) from the Panjab Raven (*Corvus corax laurencei* Hume: Corvidae) and the Eastern Rook (*Corvus frugilegus tschusii* Hartert: Corvidae).
- M. gulabimaina* sp. nov. from the Rosy Starling (*Pastor roseus* (Linn.): Sturnidae).
- M. guldum* sp. nov. from the Panjab Red-vented Bulbul (*Molpastes cafer intermedius* (Jerdon): Pycnonotidae).
- M. himalayicus* sp. nov. from the Himalayan Starling (*Sturnus vulgaris humii* Brooks: Sturnidae).
- M. masudi* Qadri from the Common Indian House Crow (*Corvus s. splendens* Vieill.: Corvidae).
- Menacanthus quadrifasciatum* (Piaget) from the Common Indian House Sparrow (*Passer domesticus indicus* Jard. and Selby: Fringillidae).
- M. safedgal* sp. nov. from the Himalayan White-cheeked Bulbul (*Molpastes l. leucogenys* (Gray): Pycnonotidae).
- M. spiniferum* (Piaget) from the Common Indian Minor (*Acridotheres t. tristis* (Linn.): Sturnidae).
- Menacanthus* sp. from the Indian Yellow-throated Sparrow (*Gymnoris x. xanthocollis* (Burt.): Fringillidae).
- Menopon gallinae* (Linn.) from the Common House Hen (*Gallus g. domesticus* Linn.: Phasianidae).
- M. interpositus* sp. nov. from the Northern Grey Partridge (*Francolinus pondicerianus interpositus* Hart.: Phasianidae).
- M. phaeostomum* (Nitzsch) from the Common Pea-fowl (*Pavo c. cristatus* Linn.: Phasianidae).
- Menopon* sp. from the Common Northern Chukor (*Alectoris gracca pallescens* (Hume): Phasianidae).
- Myrsidea (Alcedinophilus) kulucensis* sp. nov. from the Himalayan Great Pied Kingfisher (*Ceryle lugubris guttulata* Stej.: Alcedinidae).
- Myrsidea brunnea* (Nitzsch) from the Himalayan Nut-cracker (*Nucifraga caryocatectes hemispila* Vigors: Corvidae).
- M. chilchil* sp. nov. from the Common Babbler (*Argyus c. caudata* (Dumont): Timaliidae).
- M. cucullaris* (Nitzsch) from the Himalayan Starling (*Sturnus vulgaris humii* Brooks: Sturnidae).
- M. dukhunensis* sp. nov. from the Indian White Wag-tail (*Motacilla alba dukhunensis* Sykes: Motacillidae).
- M. flavirostratus* sp. nov. from the Yellow-billed Magpie (*Urocissa f. flavirostris* (Blyth): Corvidae).
- M. lyallpurensis* sp. nov. from the Common Indian Minor (*Acridotheres t. tristis* (Linn.): Sturnidae).
- M. mesoleuca* (Nitzsch) from the Eastern Rook (*Corvus frugilegus tschusii* (Hart.): the Punjab Raven (*Corvus corax laurencei* (Hume): and the Common Indian House Crow (*Corvus s. splendens* Vieill.); all Corvidae).
- M. satbhai* sp. nov. from the Bengal Jungle Babbler (*Turdoides terricolor sindianus* Ticehurst: Timaliidae).
- M. sehri* sp. nov. from the Simla Streaked Laughing Thrush (*Trochalopteron lineatum grisescentior* (Hart.): Timaliidae).
- M. sultanpurensis* sp. nov. from the Himalayan Whistling Thrush (*Myophonus coeruleus temminckii* Vigors: Turdidae).
- Myrsidea* sp. from the Indian Red-billed Blue Magpie (*Urocissa erythrorhyncha occipitalis* (Blyth.): Corvidae) and the Eastern Indian Red Start (*Phoenicurus ochruros rufiventris* (Vieill.): Turdidae).
- Neomenopon baktitar* sp. nov. from the Indian Common Sand Grouse (*Pterocles exustus erlangeri* Neum.: Pteroceliidae).
- Pseudocapoccephalus doriabagla* sp. nov. from the Indian Cattle Egret (*Bubulcus ibis coromandus* (Bodd.): Ardeidae).
- Trinoton querquedulae* (Linn.) from the Common Teal (*Nettion c. crecca* (Linn.)); the Dun Bird (*Nyroca f. ferina* (Linn.)) and the Ruddy Sheldrake (*Casarca ferruginea* Vieill.): all Anatidae; and the Himalayan Whistling Thrush (*Myophonus coeruleus temminckii* Vigors: Turdidae)—? Straggler.

Uchida abdominalis var. *indicus* nov. from the Common Grey Quail (*Coturnix c. coturnix* Linn.: Phasianidae).

U. kalatitar sp. nov. from the Indian Black Partridge (*Francolinus f. asiae* Bonap.: Phasianidae).

VI. BIRD-HOSTS INDEX WITH MALLOPHAGAN PARASITES.

PASSERES

Corvidae:

1. *Corvus corax laurencei* Hume (Punjab Raven)
Menacanthus gonophoeus (Burm.),
Allocolpocephalum subaequale (Nitzsch),
Myrsidea mesoleuca (Nitzsch).
2. *Corvus frugilegus tchusii* Hartert (Eastern Rook)
Menacanthus gonophoeus (Burm.),
Myrsidea mesoleuca (Nitzsch).
3. *Corvus s. splendens* Vieill (Indian Common House Crow)
Menacanthus masudi Qadri,
Allocolpocephalum subaequale (Nitzsch),
Myrsidea mesoleuca (Nitzsch).
4. *Urocissa erythrorhyncha occipitalis* (Blyth) (Indian Red-billed Blue Magpie),
Myrsidea sp.
5. *Urocissa f. flavirostris* (Blyth) (Yellow-billed Magpie)
Myrsidea flavirostratus sp. nov.
6. *Nucifraga caryocates hemispila* Vigors (Himalayan Nut-cracker)
Myrsidea brunnea (Nitzsch).

Timaliidae:

7. *Trichalopteron lineatum griseiventris* (Hart.) (Simla Streaked Laughing Thrush)
Myrsidea sehri sp. nov.
8. *Turdoides terricolor sindianus* Ticehurst (Sindh Jungle Babbler)
Myrsidea satbhai sp. nov.
9. *Argya c. caudata* (Dumont) (Common Babbler)
Myrsidea chilchil sp. nov.

Pycnonotidae:

10. *Molpastes cafer intermedius* (Jordon) (Punjab Red-vented Bulbul)
Menacanthus guldim sp. nov.
11. *Molpastes l. leucogenys* (Gray) (Himalayan White-cheeked Bulbul)
Menacanthus safedgal sp. nov.

Turdidae:

12. *Phoenicurus ochruros rufiventris* (Vieill.) (Eastern Indian Red-Start)
Myrsidea sp.
13. *Turdus atrogularis* Temm. (Black-throated Thrush)
Menoponidae.
14. *Myophonus coeruleus temminckii* Vigors (Himalayan Whistling Thrush)
Trinoton querquedulae (Linn.)—? Straggler.

Laniidae:

15. *Lanius excubitor lahtora* (Sykes) (Indian Great Grey Shrike)
Menacanthus dudiyalatora sp. nov.

Dicruridae:

16. *Dicrurus macrocercus peninsularis* Ticehurst (Indian Black Drongo)
Menoponidae.

Sturnidae:

17. *Pastor roseus* (Linn.) (Rose-coloured Starling)
Menacanthus gulabimaina sp. nov.
18. *Sturnus vulgaris humii* Brooks (Himalayan Starling)
Menacanthus himalayicus sp. nov.
Myrsidea cucullaris (Nitzsch).
19. *Acridotheres t. tristis* Linn. (Common Indian Minor)
Menacanthus spiniferum (Piaget),
Myrsidea lyallpurensis sp. nov.

Fringillidae:

20. *Gymnoris x. xanthocollis* (Burt.) (Indian Yellow-throated Sparrow)
Menacanthus sp.
21. *Passer domesticus indicus* Jard. & Selby (Indian House Sparrow)
Menacanthus quadrispasiatum (Piaget).

Motacillidae:

22. *Motacilla alba dukhunensis* (Sykes) (Indian White Wag-tail)
Myrsidea dukhunensis sp. nov.

CORACIIFORMES: PICI

Picidae:

23. *Picus s. squamatus* Vigors (Himalayan Scaly-bellied Green Wood-pecker)
Cuculiphilus (Picusphilus) tirkhan sp. nov.
24. *Brachypternus benghalensis* Linn. (Northern Golden-backed Wood-pecker)
Menoponidae.

CUCULI

Cuculidae:

25. *Heiropoccyx varius* Vahl. (Common Hawk Cuckoo)
Cuculiphilus upak sp. nov.
26. *Clamator j. jacobinus* (Bodd.) (Indian Pied Crested Cuckoo)
Cuculiphilus pupiya sp. nov.
27. *Eudynamis s. scolopaceus* (Linn.) (Indian Koil)
Menoponidae.

CORACII

Coraciidae:

28. *Coracias b. benghalensis* Linn. (Indian Roller)
Menoponidae.

Meropidae:

29. *Merops o. orientalis* Lath. (Indian Green Bee-eater)
Menoponidae.

Alcedinidae:

30. *Ceryle lugubris guttulata* Stej. (Himalayan Great Pied Kingfisher)
Myrsidea (Alcediniphilus) kuluensis sp. nov.

STRIGES

Tytonidae:

31. *Tyto albastretens* Hartert (Indian Barn Owl)
Cuculiphilus (Uluoecus) sp.

Asionidae:

32. *Bubo' b. bengalensis* (Frankl.) (Great Horned Owl)
Cuculiphilus (Uluoecus) sp.
33. *Athene brama indica* (Frankl.) (Northern Spotted Owlet)
Cuculiphilus (Uluoecus) panjabensis sp. nov.

ACCIPITRES

Aegypiidae:

34. *Gyps himalayensis* Hume (Himalayan Griffon Vulture)
Columbimenopon chanabensis sp. nov. (? Straggler),
Colpocephalum sp.,
Laemobothrion sp.

Falconidae:

35. ~~*Falco*~~ *jagger* Gray (Lagger Falcon)
Colpocephalum sp.,
Laemobothrion tinnunculi (Linn.)
36. *Milvus migrans govinda* Sykes (Common Pariah Kite)
Colpocephalum trinctum Nitzsch,
Laemobothrion titan (Piaget).

COLUMBAE

Columbidae:

37. *Columba livia intermedia* Strick. (Indian Blue Rock Pigeon)
Columbimenopon sp.
38. *Streptopelia d. decaocta* (Frisal.) (Indian Ring Dove)
Columbimenopon modestus sp. nov.

PTEROCLETES

Pteroclididae:

39. *Pterocles exustus erlangeri* Neum. (Indian Common Sand Grouse)
Neomenopon haktitar sp. nov.

GALLINAE & ALECTOROPODES

Phasianidae:

40. *Pavo c. cristatus* Linn. (Common Pea-fowl)
Galliferrisia tauri sp. nov.,
Menopon pharostomum Nitzsch.
41. *Gallus g. domesticus* (Linn.) (Common House Hen)
Pomacanthus stramineus (Nitzsch),
Menopon gallinae (Linn.).
42. *Coturnix c. coturnix* (Linn.) (Common Gray Quail)
Uchida abdominalis var. *indicus* nov.
43. *Alectoris graeca pallescens* (Hume) (Northern Chukor)
Menopon sp.
44. *Francolinus f. asiæ* Bonap. (Indian Black Partridge)
Uchida kalatitar sp. nov.
45. *Francolinus pondicerianus interpositus* Hart. (Northern Gray Partridge)
Menopon interpositus sp. nov.

CHARADRIIFORMES: LAROLIMICOLAE

Glareolidae:

46. *Cursorius cursor cursor* (Lath.) (Cream-coloured Courser)
Austromenopon cursorius (Giebel).

LIMICOLAE

Charadriidae:

47. *Himantopus h. himantopus* (Linn.) (Black-winged Stilt)
Actornithophilus affine (Nitzsch),
Austromenopon icterum (Nitzsch).

Scolopacidae:

48. *Tringa ochrophus* Linn. (Green Sand piper)
Actornithophilus affine (Nitzsch),
Austromenopon icterum (Nitzsch).
49. *Erolia m. minuta* (Lacst.) (Little Stint)
Actornithophilus trilobatus (Giebel).

HERODIONES: ARDEAE

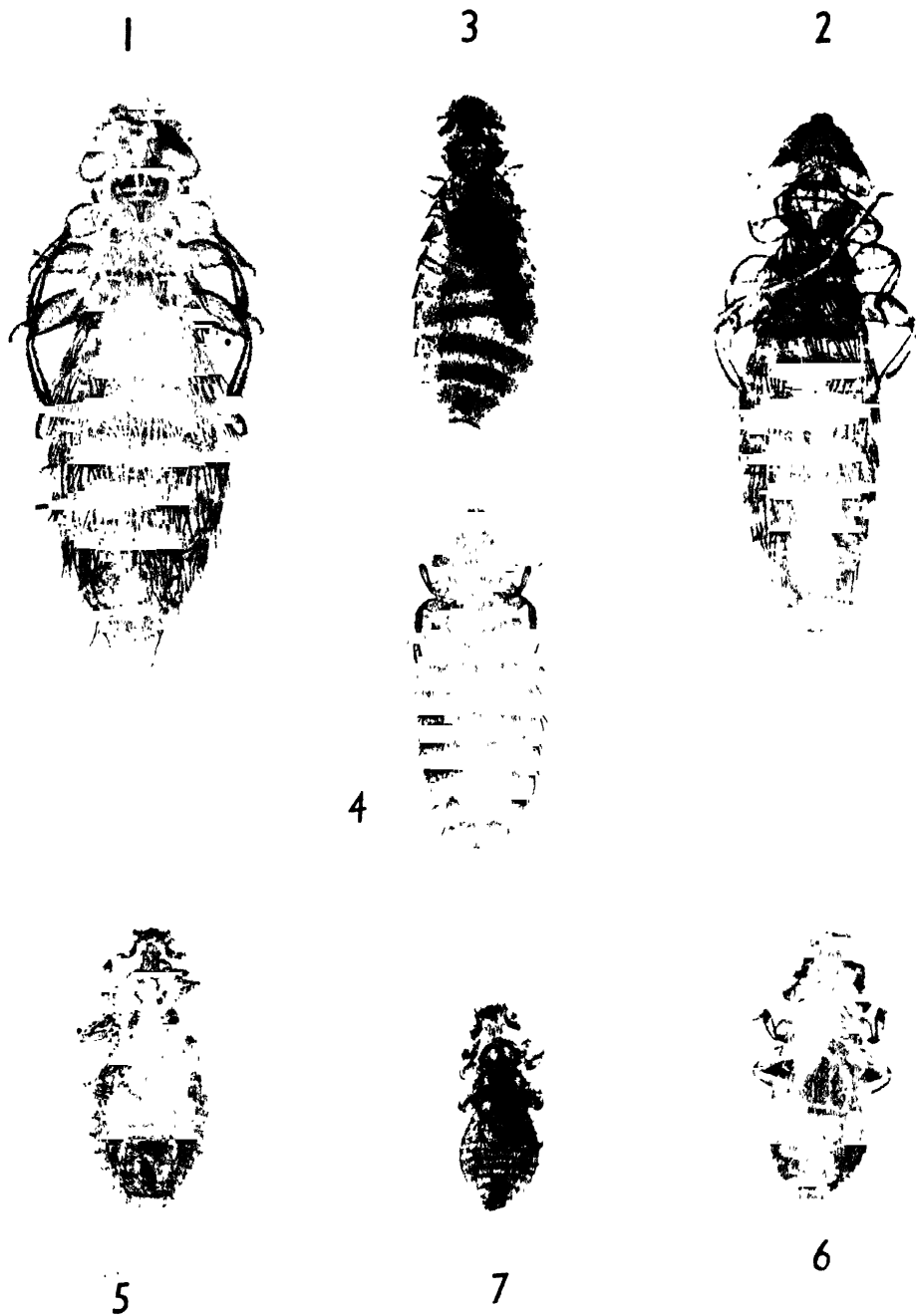
Ardeidae:

50. *Bubulcus ibis coromandus* (Bodd.) (Indian Cattle Egret)
Pseudocolpoccephalum doriabagla sp. nov.
51. *Ardeola grayii* (Sykes) (Indian Pond Heron)
Ardeiphilus trochioxus (Nitzsch).

ANSERES

Anatidae:

52. *Caurea ferruginea* (Vroeg) (Ruddy Sheldrake)
Trinoton querquedulae (Linn.).
53. *Nettion c. crecca* (Linn.) (Common Teal)
Trinoton querquedulae (Linn.).
54. *Nyroca f. ferina* (Linn.) (Poehard or Dun Bird)
Trinoton querquedulae (Linn.).



1. Female of *Eumecurus anthracinus* (Nitzsch) — 34;
2. Male of *Eumecurus anthracinus* (Nitzsch) — 30;
3. Female of *Mecurus anthracinus* sp. nov. — 23;
4. Male of *Mecurus anthracinus* sp. nov. — 28;
5. Female of *Mecurus anthracinus* sp. nov. — 23;
6. Female of *Mecurus anthracinus* sp. nov. — 23;
7. Male of *Mecurus anthracinus* sp. nov. — 23.

VII. LITERATURE.

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LETTERING AND EXPLANATION OF FIGURES.

- ac. .. conspicuous lateral bulbous capsule in *Laemobothorion* or groove or furrow on the ventral surface of the head for reception of antenna in Amblyceron Mallophaga, bound on each side by the facial ridge.
- ah. .. aster of heavy, needle-like spines on a flattened callosity.
- an. .. antenna, 4-5 jointed.
- ar. .. arolium on the tarsi.
- bh. .. ventral patch of hairs on posterior femora and several abdominal sternites.
- bl. .. large, irregular spot, mark or blotch.
- bp. .. basal plate; the chitinated basal phallic sclerite in the wall of the genital chamber, highly variable in development, sometimes a large structure supporting the unjointed organ of the male, to the proximal part of which are attached the working parts of the genital armature of the male.
- ch. .. combs of hairs on each side of some abdominal sternites and on ventral aspect of posterior femora.
- cl. .. claw.
- co. .. coxa; first easily seen joint of the leg, actually attached to the thorax.
- dp. .. see tp.

- en.* .. endomeres, endomeral plate; the thickened sclerite and at the base of the parameres which support the penis and accessory parts.
ey. .. eye.
ft. .. prosternum; fore breast; ventral sclerite between the foot jaws.
fe. .. femur, femora; the first conspicuous long joint of the legs, nearly always the strongest of all, preceded by the coxa and the very small connecting joint between these two called the trochanter and followed by tibia; thigh.
ff. .. see *tf.*
fg. .. the chitinated sclerite derived from the sternum of certain (vii-viii) abdominal segments, lying under the genital organs of the female. Female genital plate.
gp. .. gular plate; ventrally situated sclerite between the ventral occipital bands which run from the occipital margin to the base of mandibles; throat sclerite forming the central part of the ventral hind-head.
g. .. gastric teeth; a dense row of teeth and dentate flaps visible through the integument of the first or second abdominal segments in the position occupied by crop.
hb. .. the thickened and heavily pigmented, narrow, transverse sclerite.
hc. .. fringes of stout setae curving upwards around the sides of last abdominal segments.
lb. .. lateral bands; paratergal plates; lateral plates; pleural plates; heavily pigmented lateral sclerites of the abdominal segments.
lr. .. the upper lip covering the mandibles, labrum.
ma. .. mandibles.
me. .. median notch; emargination.
mr. .. the ventral sclerite or breast plate of the third or posterior thoracic ring; metasternum.
ms. .. the ventral surface of the middle thoracic ring; mesosternum.
mt. .. the second or middle, thoracic ring which bears the second pair of legs, usually united with posterior thoracic ring; mesothorax.
m.x. .. the third or posterior thoracic ring which bears the hind pair of legs, usually fused with mesothorax and signifies the compound thoracic segment pterothorax; metathorax.
ob. .. ocular blotch; a round, cut off temporal band close to the anterior extremities of dorsal occipital band.
of. .. ocular fleck; a small, almost rounded spot of pigment near the eye.
oh. .. ocular fringe; closely set small hairs on posterior half of ocular emargination in Amblycoron Mallophaga, sometimes extending as far as temporal margins.
ol. .. ocular slit.
on. .. ocular notch.
pa., pn. .. parameres, the lateral, longer processes or plates, usually cultiform or falcate appendages of the genital armature which enclose the endomeral plates and serve to open the genital aperture of the female during copulation and facilitate the working of intromittent organ of male.
pb. .. preputial sac; the endophalus, the inner chamber of the phallus (intromittent organ of the male, penis) invaginated at the end of the aedagus, into which the ejaculatory duct opens; typically an aversible sac on tube but sometimes a permanently internal structure.
pf. .. prothorax; the first segment of the thorax, bearing the anterior pair of legs (foot jaws).
pg., ps. .. pharyngeal sclerite and glands; oesophageal sclerite a greatly developed thickening of the chitinous lining of the anterior part of the oesophagus, visible just behind the mandibles; the conspicuous sclerotic pharyngeal armature.
pm. .. sensitive organs of appreciation, articulating and attached to the maxillae; maxillary palp.
pn. .. see *pa.*
pp. .. paratergal plates; lateral plates; pleural plates; lateral bands.
ps. .. see *pg.*
pt., tt. .. pterothorax; meso- and meta-thorax fused together.
px. .. pericoxal plates; intercoxal line; intercoxal band; thickened, heavily pigmented sclerite of ventral surface of the thorax running transversely between the coxae of the same side.
sm. .. sternal markings; sternal blotches; the pigmented median, ventral plates.
st. .. the lower surface of abdominal segments; sternum.
ta. .. transverse abdominal bands.
te., tl. .. temples; lateral plates, each of which covers rather major portion of the surface and is limited internally by the dorsal occipital band; temporal lobes.
tf. ff. .. fringe of fine hairs on the last abdominal segment.
th. .. transverse row of hairs.
ti. .. tibia; the second of the long conspicuous division of the legs, generally longer and narrower than the femora.
tl. .. see *te.*

- tp.*, *dp.* .. tergal plates; transverse blotches; transverse bands; the dorsal pigmented sclerites of the abdominal segments, lying between the lateral or pleural plates; these may be entire, median or confined on the lateral or submedian region of the abdominal segments.
- tr.* .. trochanter; very small connecting joint between coxa and femur.
- tt.* .. see *pt.*
- tu.* .. tarsus, the last joint of the legs.
- vs.* .. peg-like rectate, recumbent process arising ventrally from a position behind the palpi.

VERTICAL PROPAGATION OF ELECTROMAGNETIC WAVES IN THE IONOSPHERE

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SUMMARY

A connected discussion of the equations for the vertical propagation of e.m. waves in the ionosphere is given in standardised notation. It is shown that the electric field vector components E_x and E_y are coupled by polarisation terms, ρ_1, ρ_2 which are functions of G.M. latitude and height; and the propagation vectors, V and W , equal respectively to $(E_x + i\rho E_y)/\sqrt{1+\rho^2}$, for two values of ρ , are governed by two refractive indices q_0, q_s and a coupling term ϕ ; V and W may be identified with o - and e -waves respectively. The five quantities needed to define wave propagation completely are $\rho_1, \rho_2, \phi, q_0$ and q_s ; we have given a detailed discussion of the first three, and have omitted discussions about q_0 and q_s which are identical with those given by Appleton and have been discussed in detail by Booker (1935) and others. It is shown that the coupling term ϕ can be neglected everywhere for F -layer propagation except very near the G.M. poles, while the E -layer propagation is more difficult to handle.

INTRODUCTION.

Wave equations for the propagation of e.m. waves in the ionosphere had been given by Hartree (1929), Epstein (1930), Försterling (1931), Saha and Rai (1937), Rawer (1939) and Rydbeck (1940) and more recently by B. K. Bannerjea (1947). Most of the older investigations were confined to the particular case of vertical propagation in the magnetic equator or poles. In recent years vertical propagation in any latitude has been tackled by Rydbeck (1942) and by Saha, Bannerjea, Guha (1947), but a full discussion of the equations is still wanting. We discuss here the exact equations from a standpoint which is likely to throw light on the nature of modification of wave propagation at high geomagnetic latitudes.

§1. DEDUCTION OF EQUATIONS OF WAVE PROPAGATION.

The deduction of the equations of propagation of e.m. waves in the ionosphere follows from the usual method of e.m. theory of light. We start with the Maxwell's equations:

$$\begin{aligned}\nabla \times \mathbf{H} &= \frac{1}{c} \frac{\partial \mathbf{D}}{\partial t}; & \nabla \times \mathbf{E} &= -\frac{1}{c} \frac{\partial \mathbf{H}}{\partial t} \\ \nabla \cdot \mathbf{D} &= 0; & \nabla \cdot \mathbf{H} &= 0; & \mathbf{D} &= \mathbf{E} + \mathbf{P} = \mathbf{K} \cdot \mathbf{E}.\end{aligned}\tag{1.1}$$

It will be presently shown that the dielectric constant \mathbf{K} is a tensor quantity. Here \mathbf{P} is the polarisation vector due to the displacement of electrons by the electric

field of the wave as modified by the presence of the earth's magnetic field. If \mathbf{S} denotes the displacement of the electron under these conditions, we have

$$\mathbf{P} = 4\pi Ne\mathbf{S} \quad \dots \quad \dots \quad \dots \quad \dots \quad (1.2)$$

The displacement \mathbf{S} is given by the Lorentz equation

$$\frac{d^2\mathbf{S}}{dt^2} + \nu \frac{d\mathbf{S}}{dt} + \frac{e}{mc} \left[\mathbf{H} \times \frac{d\mathbf{S}}{dt} \right] = \frac{e}{m} \cdot \mathbf{E} \quad \dots \quad \dots \quad \dots \quad (1.3)$$

Replacing \mathbf{S} by \mathbf{P} and since $\mathbf{E}, \mathbf{S} \propto e^{ipt}$ we can easily find out the solution of (1.3) in the form

$$\mathbf{P} = A \cdot \Delta \mathbf{E}, \quad (1.2a)$$

where $A = r/\beta(\beta^2 - \omega^2)$ and Δ is a tensor quantity given by the matrix

$$\Delta = \begin{pmatrix} \omega_x^2 - \beta^2 & \omega_y\omega_z + i\beta\omega_x & \omega_z\omega_x - i\beta\omega_y \\ \omega_x\omega_y - i\beta\omega_z & \omega_y^2 - \beta^2 & \omega_z\omega_y + i\beta\omega_x \\ \omega_x\omega_z + i\beta\omega_y & \omega_y\omega_z - i\beta\omega_x & \omega_z^2 - \beta^2 \end{pmatrix} \quad (1.4)$$

Here $\beta = 1 - i\nu/p$ where ν = collision-frequency, $r = p_0^2/p^2$ where $p_0^2 = 4\pi Ne^2/m$, N being the number of particles per c.c., $\omega = \mathbf{p}_h/p$ where \mathbf{p}_h = circular gyromagnetic frequency = $e\mathbf{H}/mc$, $\omega_x, \omega_y, \omega_z$ are components of ω .

From (1.1), (1.2) and (1.4) we can write the complex dielectric tensor in the form

$$\mathbf{K} = \begin{pmatrix} 1 - A(\beta^2 - \omega_x^2) & A(\omega_x\omega_y + i\beta\omega_z) & A(\omega_z\omega_x - i\beta\omega_y) \\ A(\omega_x\omega_y - i\beta\omega_z) & 1 - A(\beta^2 - \omega_y^2) & A(\omega_z\omega_y + i\beta\omega_x) \\ A(\omega_x\omega_z + i\beta\omega_y) & A(\omega_z\omega_y - i\beta\omega_x) & 1 - A(\beta^2 - \omega_z^2) \end{pmatrix} \quad (1.4a)$$

So far the treatment has been quite general. Let us now consider the propagation of a plane wave along the vertical directions (axis of z) and the axis of y is chosen to be perpendicular to the magnetic meridian. Then putting $\omega_y = 0$, \mathbf{K} comes out as

$$\mathbf{K} = \begin{pmatrix} 1 - A(\beta^2 - \omega_x^2) & A i \beta \omega_z & A \omega_z \omega_x \\ -A i \beta \omega_z & 1 - A \beta^2 & A i \beta \omega_x \\ A \omega_x \omega_z & -A i \beta \omega_x & 1 - A(\beta^2 - \omega_z^2) \end{pmatrix} \quad \dots \quad \dots \quad (1.4b)$$

Introducing the condition $\nabla \cdot \mathbf{D} = 0$, i.e. $E_z + P_z = 0$ we get from (1.4b)

$$E_z = \frac{r\omega_z}{C'} (-\omega_z E_z + i\beta E_y) \quad (1.5)$$

where

$$C' = \beta(\beta^2 - \omega^2) - r(\beta^2 - \omega_z^2)$$

Taking the curl of both sides of the second equation in (1.1) and putting $\frac{\partial}{\partial t} = ip$ we get the wave equation for the electric vector in the form

$$\nabla \times \nabla \times \mathbf{E} - \frac{p^2}{c^2} \mathbf{D} = 0 \quad \dots \quad \dots \quad \dots \quad (1.6)$$

Breaking up this equation into components and putting $\frac{\partial}{\partial x} = \frac{\partial}{\partial y} = 0$ we get

$$\frac{d^2 E_x}{dz^2} + \frac{p^2}{c^2} D_x = 0, \quad \frac{d^2 E_y}{dz^2} + \frac{p^2}{c^2} D_y = 0 \quad \dots \quad (1.7)$$

From (1.6) and (1.7) we get after some simplification the following expressions for the Maxwell Displacement Vector

$$\begin{aligned} D_x &= K_1 E_x - iL E_y, & D_y &= K_2 E_y + iL E_x \\ K_1 &= 1 - r \frac{\beta^2 - r\beta - \omega_x^2}{C'}, & K_2 &= 1 - \frac{r(\beta^2 - r\beta)}{C'} \\ L &= r(r - \beta)\omega_x / C' \end{aligned} \quad (1.8)$$

Introducing the symbol $u = zp/c$, we get the equations of propagation of the electric vector as

$$\frac{d^2 E_x}{du^2} + K_1 E_x - iL E_y = 0; \quad \frac{d^2 E_y}{du^2} + K_2 E_y + iL E_x = 0 \quad \dots \quad (1.9)$$

Equations in these forms do not help us much in the understanding of the phenomenon unless the coupling term L vanishes, or $K_1 = K_2$. We have $L = 0$ when $\omega_x = 0$, i.e. at the magnetic equator (quasi-transverse case).

$K_1 = K_2$ when $\omega_x = 0$; this holds only for the magnetic poles (quasi-longitudinal case). These special cases are given in equations (1.17), (1.16).

For any latitude we try the following procedure. Multiply both sides of the second equation in (1.9) by some indeterminate quantity $i\rho$ and add the product to the first equation. Re-arranging the terms we get

$$\frac{d^2}{du^2} (E_x + i\rho E_y) + (K_1 - \rho L) E_x + (K_2 - L/\rho) i\rho E_y - 2i \frac{d\rho}{du} \frac{dE_y}{du} - i \frac{d^2 \rho}{du^2} E_y = 0 \quad \dots \quad (1.10)$$

Since we are free to choose ρ , it is advantageous to do it in such a way that the coefficients of E_x and $i\rho E_y$ are equal, i.e. we put

$$K_1 - \rho L = K_2 - L/\rho = q^2. \quad \dots \quad (1.11)$$

ρ is therefore given by the roots of the equation

$$\rho^2 - (K_1 - K_2)\rho/L - 1 = 0 \quad \dots \quad (1.12)$$

Now introducing the symbol

$$G = (K_1 - K_2)/2L = \frac{\omega_x^2}{2\omega_x(r - \beta)} \quad \dots \quad (1.13)$$

the two roots of equation (1.11), which can be denoted by ρ_1 and ρ_2 , can be written as:

$$\rho_1 = G - \sqrt{1 + G^2}; \quad \rho_2 = G + \sqrt{1 + G^2} \quad \dots \quad (1.14)$$

Now it can be easily shown that

$$C' = (\beta - r)(\beta + \rho_1 \omega_x)(\beta + \rho_2 \omega_x).$$

With the aid of this relation, it is easy to prove from (1.11) that q^2 has two values q_o^2 and q_e^2 given by

$$q_o^2 = 1 - \frac{r}{\beta + \rho_1 \omega_x}, \quad q_e^2 = 1 - \frac{r}{\beta + \rho_2 \omega_x}. \quad \dots \quad (1.14a)$$

It is easy to see that these expressions are equivalent to Appleton expressions for (complex refractive index)². (Vide the expression given by him in the Report on the Progress of Physics, Vol. 2, 1936.)

We may now turn to the equations (1.10). If $d\rho/du$ and $d^2\rho/du^2$ can be neglected, we have the following equations of propagation for the two waves

$$\left. \begin{aligned} O\text{-wave:} & \quad \frac{d^2}{du^2} (E_x + i\rho_1 E_y) + q_o^2 (E_x + i\rho_1 E_y) = 0 \\ X\text{-wave:} & \quad \frac{d^2}{du^2} (E_x + i\rho_2 E_y) + q_s^2 (E_x + i\rho_2 E_y) = 0 \end{aligned} \right\} \dots (1.15)$$

The terms we have neglected are

$$-2i \cdot \frac{d\rho}{du} \cdot \frac{dE_y}{du} - i \frac{d^2\rho}{du^2} E_y.$$

Now we have

$$\frac{d\rho}{du} = \frac{d}{du} (G \mp \sqrt{1+G^2}) \simeq \frac{dr}{dz} \simeq \frac{dN}{dz}$$

and can be neglected only when $\frac{dN}{dz} = 0$ or small. Equations (1.15) therefore hold when we can neglect dN/dz and d^2N/dz^2 , i.e. for a medium for which N varies very slowly.

The equations (1.15) take simplified forms at the geomagnetic equator and the poles. For the GM-equator we have, since $G = \infty$,

$$\rho_1 = G - \sqrt{1+G^2} = 0, \quad \omega_s \rho_2 = 2G\omega_s = \frac{\omega^2}{r-\beta}$$

Hence we have

$$q_o^2 = 1 - \frac{r}{\beta}, \quad q_s^2 = 1 - \frac{r}{\beta - \frac{\omega^2}{\beta - r}}$$

and the equations (1.15) have the form

$$\left. \begin{aligned} (O\text{-wave}): & \quad \frac{d^2 E_x}{du^2} + \left(1 - \frac{r}{\beta}\right) E_x = 0 \\ (X\text{-wave}): & \quad \frac{d^2 E_y}{du^2} + \left(1 - \frac{r}{\beta - \frac{\omega^2}{\beta - r}}\right) E_y = 0 \end{aligned} \right\} \dots (1.16)$$

For the poles, we have $G = 0$, $\rho_2 = 1$, $\rho_1 = -1$, and $\omega_s = -\omega$ at the north pole, and $= \omega$ at the south pole. Hence we have the equations

$$\left. \begin{aligned} (O\text{-wave}): & \quad \frac{d^2}{du^2} (E_x - iE_y) + \left(1 - \frac{r}{\beta \pm \omega}\right) (E_x - iE_y) = 0 \\ (X\text{-wave}): & \quad \frac{d^2}{du^2} (E_x + iE_y) + \left(1 - \frac{r}{\beta \mp \omega}\right) (E_x + iE_y) = 0 \end{aligned} \right\} \dots (1.17)$$

The upper sign refers to the N-magnetic pole, the lower to the S-magnetic pole.

More rigorous equations of propagation can be deduced by rotating the axes through a complex angle ϕ . We start from (1.9) and put

$$\begin{pmatrix} E_x \\ iE_y \end{pmatrix} = \begin{pmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{pmatrix} \begin{pmatrix} V \\ W \end{pmatrix} = S \begin{pmatrix} V \\ W \end{pmatrix}$$

where S denotes the matrix given above. The inverse matrix

$$S^{-1} = \begin{pmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{pmatrix} \text{ and we have } \begin{pmatrix} V \\ W \end{pmatrix} = S^{-1} \begin{pmatrix} E_x \\ iE_y \end{pmatrix}$$

Then it can be easily shown that if by \dot{E}_x we denote $\frac{dE_x}{du}$, etc.

$$\begin{pmatrix} \dot{E}_x \\ i\dot{E}_y \end{pmatrix} = S \begin{pmatrix} V' \\ W' \end{pmatrix}, \quad \begin{pmatrix} \ddot{E}_x \\ i\ddot{E}_y \end{pmatrix} = S \begin{pmatrix} V'' \\ W'' \end{pmatrix}$$

where

$$\dot{V} = \frac{dV}{du}, \quad \ddot{V} = \frac{d^2V}{du^2}, \text{ etc. ;}$$

$$V' = \dot{V} - \dot{\phi} W, \quad W' = \dot{W} + \dot{\phi} V;$$

$$V'' = \frac{dV'}{du} - \dot{\phi} W' = \ddot{V} - 2\dot{\phi} \dot{W} - \ddot{\phi} W - \dot{\phi}^2 V;$$

$$W'' = \frac{dW'}{du} + \dot{\phi} V' = \ddot{W} + 2\dot{\phi} \dot{V} + \ddot{\phi} V - \dot{\phi}^2 W.$$

It is easy to see that V' , W' are the moving co-ordinate derivatives of V and W .

Hence the fundamental equations (1.9) can be written as

$$(V'' + K_1 V - LW) \cos \phi - (W'' + K_1 W + LV) \sin \phi = 0, \quad (1.18)$$

$$(V'' + K_2 V + LW) \sin \phi - (W'' + K_2 W - LV) \cos \phi = 0.$$

From these equations, it is easy to deduce the following equations:

$$V'' + \{K_1 \cos^2 \phi + K_2 \sin^2 \phi - 2L \sin \phi \cdot \cos \phi\} V - \{(K_1 - K_2) \sin \phi \cdot \cos \phi + L (\cos^2 \phi - \sin^2 \phi)\} W = 0. \quad \dots (1.19a)$$

$$W'' + \{K_1 \sin^2 \phi + K_2 \cos^2 \phi + 2L \sin \phi \cos \phi\} W - \{(K_1 - K_2) \sin \phi \cdot \cos \phi + L (\cos^2 \phi - \sin^2 \phi)\} V = 0 \quad \dots (1.19b)$$

We observe that the coefficients of cross-terms, i.e. of W in (1.19a) and of V in (1.19b) have the same value. This may be made to vanish by appropriate choice of ϕ ,

$$\text{i.e. putting } (K_1 - K_2)/2L = G = -\cot 2\phi \quad \dots \dots \dots (1.20)$$

If we put $\tan \phi = \tau$, the above equation is equivalent to $\tau^2 - 2\tau G - 1 = 0$, or $\tau = \tan \phi = G \pm \sqrt{1 + G^2} = \rho_1, \rho_2$

As before, we denote by ρ_1 the quantity $G + \sqrt{1 + G^2}$. Then the other value of

$$\tau = -\frac{1}{\rho_1} = \rho_2 = G + \sqrt{1 + G^2}.$$

It can be easily shown that the coefficients of V and W in (1.19a) and (1.19b) viz.,

$$K_1 \cos^2 \phi + K_2 \sin^2 \phi - 2L \sin \phi \cdot \cos \phi = q_o^2$$

$$K_1 \sin^2 \phi + K_2 \cos^2 \phi + 2L \sin \phi \cdot \cos \phi = q_e^2$$

We have therefore the final equations:

$$V'' + q_o^2 V = 0; \quad W'' + q_e^2 W = 0$$

Now

$$V = E_x \cos \phi + iE_y \sin \phi = \frac{E_x + i\rho_1 E_y}{\sqrt{1 + \rho_1^2}}$$

$$W = -E_x \sin \phi + iE_y \cos \phi = \frac{E_x + i\rho_2 E_y}{\sqrt{1 + \rho_2^2}} \quad \dots \quad (1.21)$$

Hence the equations written in full are:—

$$\left. \begin{aligned} (O\text{-wave}) \quad & \frac{d^2 V}{du^2} + (q_o^2 - \dot{\phi}^2) V = 2\dot{\phi} \dot{W} + \ddot{\phi} W \\ (X\text{-wave}) \quad & \frac{d^2 W}{du^2} + (q_e^2 - \dot{\phi}^2) W = -2\dot{\phi} \dot{V} - \ddot{\phi} V \end{aligned} \right\} \quad \dots \quad (1.22)$$

If the coupling term $\dot{\phi} = \frac{d}{du} \tan^{-1} \rho = \frac{d\rho/du}{1 + \rho^2}$ can be put equal to zero, then

equations (1.22) reduce to the equations (1.15). The coupling term is discussed in detail in the next section.

The advisability of rotating the axes through an angle ϕ is easily suggested from analogy of the present case to that of crystal optics. We write the equation (1.7) in the form

$$\frac{d^2 \mathbf{E}}{du^2} + \mathbf{D} = 0$$

where the vector \mathbf{E} has E_x and iE_y as the components and the vector \mathbf{D} is given by

$$\begin{pmatrix} D_x \\ iD_y \end{pmatrix} = \begin{pmatrix} K_1 & -L \\ -L & K_2 \end{pmatrix} \begin{pmatrix} E_x \\ iE_y \end{pmatrix}$$

Since the tensor connecting \mathbf{D} and \mathbf{E} is a symmetrical tensor we write the equation of the tensor-ellipsoid as

$$\mathbf{D} \cdot \mathbf{E} = K_1 E_x^2 - 2LE_x \cdot iE_y + K_2 (iE_y)^2$$

from which we find out the principal axes, by the customary method of removing the cross term. We put

$$E_x = V \cos \phi - W \sin \phi, \quad iE_y = V \sin \phi + W \cos \phi.$$

This is equivalent to our transformation. The rest is identical. The tensor-ellipsoid now takes the form

$$\mathbf{D} \cdot \mathbf{E} = q_o^2 V^2 + q_e^2 W^2 = f.$$

ϕ is the angle between the major axis of the ellipse and the magnetic meridian.

* This type of equations was given by Rydbeck in 1950, but the signs of the right hand side of the two equations were given as same. This is clearly a mistake, the signs ought to be opposite.

If $\frac{dN}{dz} = 0$ it retains a constant value. (See discussion in the next section.) We observe from (1.22) that the two modes of propagation are characterised by the phase velocities c/q_o , c/q_e and their respective polarisations are given by $i\rho_1$ and $i\rho_2$ (*vide infra*.)

It is not easy to deduce simple equations for the magnetic vectors. They are of the fourth degree. But some simplified relations can be deduced from the fundamental Maxwell equations. From the relation (1.1) we have

$$\frac{dH_x}{du} = -LE_x + iK_2E_y, \quad i\frac{dH_y}{du} = K_1E_x - L \cdot iE_y,$$

or expressing E_x and iE_y in terms of V and W , we have

$$\begin{pmatrix} \dot{H}_x \\ i\dot{H}_y \end{pmatrix} = \begin{pmatrix} K_2 \sin \phi - L \cos \phi & K_2 \cos \phi + L \sin \phi \\ K_1 \cos \phi - L \sin \phi & -K_1 \sin \phi - L \cos \phi \end{pmatrix} \begin{pmatrix} V \\ W \end{pmatrix}$$

or

$$\left. \begin{aligned} V &= (\dot{H}_x \sin \phi + i\dot{H}_y \cos \phi)/q_o^2 = E_x \cos \phi + iE_y \sin \phi \\ W &= (\dot{H}_x \cos \phi + i\dot{H}_y \sin \phi)/q_e^2 = -E_x \sin \phi + iE_y \cos \phi \end{aligned} \right\} \quad \dots \quad (1.23)$$

From these expressions, which are exact, it is not possible to deduce any simple relation between the magnetic and electric vectors at any point. Only at the ground ($r = 0$) where

$$q_o^2 = q_e^2 = 1, \text{ we have } E_x = i\dot{H}_y, iE_y = \dot{H}_x \quad \dots \quad (1.24)$$

but these relations are not applicable for any other point.

§ 2. POLARISATION AND COUPLING.

Expressions (1.22) represent the most rigorous equations for vertical propagation of e.m. waves in the ionosphere. The electric vectors E_x , E_y are coupled by the quantities ρ_1 and ρ_2 forming two new vectors V and W given by (1.21) and equations for V and W are coupled by the factor $\dot{\phi}$. As shown earlier V may be identified with the electric vector for the o -mode of propagation, with the corresponding quantity W for the e -mode.

The general form of solution of (1.22) can be written in the forms:

$$\left. \begin{aligned} V &= (E_x + i\rho_1 E_y)/\sqrt{1+\rho_1^2} \simeq e^{ipt} \cdot f_V(z) \\ \text{and } W &= (E_x + i\rho_2 E_y)/\sqrt{1+\rho_2^2} \simeq e^{ipt} \cdot f_W(z) \end{aligned} \right\} \quad \dots \quad (2.1)$$

or since ρ_1 and ρ_2 are both functions of z , we can write:

$$E_x + i\rho_1 E_y \simeq e^{ipt} \cdot \psi_V(z), \quad E_x + i\rho_2 E_y \simeq e^{ipt} \cdot \psi_W(z)$$

where both ψ_V and ψ_W are complex functions of the real variable z .

Let us now put

$$i\rho_1 = Re^{i\alpha} \text{ and consequently } i\rho_2 = R^{-1}e^{-i\alpha} \quad \dots \quad (2.1a)$$

Therefore we have

$$\left. \begin{aligned} E_x \cdot e^{-ipt} + RE_y e^{-i(pt-\alpha)} &= \psi_1(z) \\ E_x \cos pt + R \cdot E_y \cos (pt-\alpha) &= Re |\psi_1(z)| = A_V \\ E_x \sin pt + RE_y \sin (pt-\alpha) &= Im |\psi_1(z)| = B_V \end{aligned} \right\} \quad \dots \quad (2.2)$$

where A and B are functions of z .

Hence we have for the V -wave:

$$E_x^V = \frac{C_V}{\sin \alpha} \sin (pt - \alpha + \pi - \theta_V), \quad E_y^V = \frac{C_V}{R \sin \alpha} \sin (pt - \theta_V) \quad \dots \quad (2.3)$$

where $C_V = \sqrt{A_V^2 + B_V^2}$, $\theta_V = \tan^{-1}(B_V/A_V)$

Similarly for the W -wave, we get

$$E_x^W = \frac{RC_W}{\sin \alpha} \sin (pt - \alpha - \theta_W), \quad E_y^W = \frac{C_W}{\sin \alpha} \sin (pt + \pi - \theta_W)$$

where

$$C_W = \sqrt{A_W^2 + B_W^2}, \quad \theta_W = \tan^{-1}(B_W/A_W) \quad \dots \quad (2.4)$$

The phase-angle α and the amplitude ratio R are in general functions of δ , ω , r and θ , and we discuss presently how to obtain analytical expressions for R and α .

Magnetic Damping Factor: We denote the magnetic condition of the locality by the angle of propagation θ , which is the angle between the upward vertical direction and the positive direction of the magnetic lines of force.

Therefore

$$\omega_s = -|\omega| \cos \theta, \quad \omega_e = -|\omega| \sin \theta \quad \dots \quad (2.5)$$

because

$$\omega = \frac{e\mathbf{H}}{mc\mathbf{p}}, \quad \text{and } e = -|e| \text{ for electrons;}$$

put

$$\nu_e = p\omega_s^2/2\omega_s = -\frac{|p_h|}{2 \cos \theta} \cdot \sin^2 \theta. \quad \dots \quad (2.6)$$

ν_e is positive in the N.H. and negative in S.H. $|\nu_e|$ varies from 0 at the poles to ∞ at the equator, and its value for a number of stations in the N.H. is shown in row 6 of Table III. Let us denote ν_e/p by δ_e which may be termed the magnetic damping ratio. Then introducing the quantities ξ and η defined by

$$\xi = \frac{\delta}{\delta_e}, \quad \eta = \frac{1-r}{\delta_e}, \quad \tan \gamma = \frac{\delta}{1-r} \quad \dots \quad (2.7)$$

we have

$$G = \frac{\delta_e}{r-\beta} = \frac{1}{-\eta+i\xi} = -\left(\frac{\eta}{\eta^2+\xi^2} + i\frac{\xi}{\eta^2+\xi^2}\right) \quad \dots \quad (2.8)$$

We shall now show that it is convenient to represent R , α and other quantities on a ξ, η -plane. Let us first discuss the possible range of values of ξ and η .

THE ξ, η -PLANE.

We have $\xi = \nu/\nu_e$; hence ξ is positive in the N.H., and negative in the S.H. $|\xi|$ varies from ∞ at the poles to 0 at the G.M.E. Large values of ξ denote large damping, small values small damping. $\xi = 0$ indicates no damping.

As $|\delta_e|$ varies from 0 at the pole to ∞ at the G.M.E., the particular values of ξ which refer to E or F -regions at any locality will have to be found for every locality separately.

Let us now trace the values $\eta = \frac{1-r}{\delta_e}$. In the N.H., since δ_e is positive, we have on the ground $r = 0$, $\eta = 1/\delta_e$. This is the maximum value of η below $r = 1$. As we take higher points in the ionosphere, $r = \frac{4\pi Nc^2}{mp^2}$ becomes appreciable, the value of η decreases and it becomes zero at $r = 1$, after which for $r > 1$, η is negative.

Therefore the line $r = 1$, which corresponds to $\eta = 0$, divides the $\xi\eta$ -plane in two parts.

Let us now try to find out general analytical expressions for R and α at any height, i.e. for any value of r and δ , as functions of ξ and η . We proceed from the expressions

$$\left. \begin{aligned} Re^{i\alpha} &= i\rho_1 = iG\{1 - \sqrt{1 + 1/G^2}\} \\ R^{-1}e^{-i\alpha} &= i\rho_2 = iG\{1 + \sqrt{1 + 1/G^2}\} \end{aligned} \right\} \dots \dots \dots (2.9)$$

Now using (2.6) and (2.7), we have

$$(R + R^{-1}) \cos \alpha + i(R - R^{-1}) \sin \alpha = 2iG$$

from which we deduce the two relations

$$(R + R^{-1}) \cos \alpha = \frac{2\xi}{\eta^2 + \xi^2}, \quad (R - R^{-1}) \sin \alpha = -\frac{2\eta}{\eta^2 + \xi^2} \dots \dots (2.10)$$

From (2.9), we deduce the important relation

$$\cos 2\alpha = \frac{1}{\lambda^2} - \sqrt{1 + \frac{2}{\lambda^2} \cos 2\gamma + \frac{1}{\lambda^4}} \dots \dots \dots (2.11)$$

where

$$\lambda^2 = \xi^2 + \eta^2$$

The sign before the radical is ± 1 . We have retained only the negative sign after comparison with the limiting case of a friction-free atmosphere. The following expressions for R can be easily verified

$$\left. \begin{aligned} R^2 &= \frac{\xi \tan \alpha - \eta}{\xi \tan \alpha + \eta} \\ R &= \frac{1}{\lambda^2} \left\{ \frac{\xi}{\cos \alpha} - \frac{\eta}{\sin \alpha} \right\} \\ R^{-1} &= \frac{1}{\lambda^2} \left\{ \frac{\xi}{\cos \alpha} + \frac{\eta}{\sin \alpha} \right\} \end{aligned} \right\} \dots \dots (2.12)$$

There are some inherent ambiguities in these expressions for R and α which must be removed. This can be done if we follow the course of the complex quantities ρ_1 and ρ_2 in the complex plane and always confine ourselves to one particular branch in discussing the nature of ρ_1 , ρ_2 .

For this purpose we start with expressions (2.9).

Now

$$1 + \frac{1}{G^2} = \{1 - \xi^2 + \eta^2\} - 2i\xi\eta \dots \dots \dots (2.13)$$

when $r = 0$, $Im\left\{1 + \frac{1}{G^2}\right\} = -2\xi\eta$ and it is definitely negative. Hence, if

we plot $1 + \frac{1}{G^2}$ in the complex plane, the point representing it must be in the third or

the fourth quadrant. Therefore, the point $\left(1 + \frac{1}{G^2}\right)^{\frac{1}{2}}$ which is double-valued, must have one of its values in the fourth quadrant, and therefore, the other will be in the second quadrant.

We now choose $\left(1 + \frac{1}{Q^2}\right)^{\frac{1}{2}}$ to be given by the point in the fourth quadrant for $r = 0$.

Now let r increase; when $r = 1$, $Im\left\{1 + \frac{1}{Q^2}\right\} = 0$ and as (2.11) shows $Re\left\{1 + \frac{1}{Q^2}\right\} > 0$ if $\xi < 1$, and < 0 if $\xi > 1$.

Hence, at $r = 0$, and for $\xi < 1$, $\left(1 + \frac{1}{Q^2}\right)^{\frac{1}{2}}$ is either real positive or real negative. But the last alternative is ruled out as we have $\left\{1 + \frac{1}{Q^2}\right\}^{\frac{1}{2}}$ in the fourth quadrant. Hence $\left(1 + \frac{1}{Q^2}\right)^{\frac{1}{2}}$ is real positive for $r = 1$, $\xi < 1$. Similarly for $\xi < 1$, $\left(1 + \frac{1}{Q^2}\right)^{\frac{1}{2}}$ is negative imaginary. For $r > 1$, and $\xi < 1$, $Im\left\{1 + \frac{1}{Q^2}\right\}$ is > 0 , and $\left(1 + \frac{1}{Q^2}\right)^{\frac{1}{2}}$ is in the first quadrant, while for $\xi > 1$, $\left(1 + \frac{1}{Q^2}\right)^{\frac{1}{2}}$ is in the third quadrant, i.e., the real part is negative.

Thus $Re\left\{1 + \frac{1}{Q^2}\right\}^{\frac{1}{2}}$ is always positive except when $\xi > 1$ and $r > 1$. In this case $Re\left\{1 + \frac{1}{Q^2}\right\}^{\frac{1}{2}}$ is negative. Now from (2.9), we have

$$\frac{|\rho_1|}{|\rho_2|} = R^2 = \left(\frac{1 - 2A \cos \beta + A^2}{1 + 2A \cos \beta + A^2}\right)^{\frac{1}{2}}$$

where $A \cos \beta = Re\left\{1 + \frac{1}{Q^2}\right\}^{\frac{1}{2}}$

Hence, in general $R^2 < 1$, except for the quadrant $\xi > 1$, $r > 1$, in which case, since $Re\left\{1 + \frac{1}{Q^2}\right\}^{\frac{1}{2}} < 0$, $R^2 > 1$.

Putting $\tan \gamma = t$, we have from (2.10)

$$\cos \alpha = \frac{1}{\xi} \cdot \frac{2t^2}{1+t^2} \cdot \frac{R}{R^2+1}$$

$$\sin \alpha = \frac{1}{\xi} \cdot \frac{2t}{1+t^2} \cdot \frac{R}{1-R^2}$$

Let us take N.H. Since ξ is positive, we have $\cos \alpha > 0$ and $\sin \alpha > 0$ for $r < 1$; and for $r > 1$ and $\eta < 1$, $\sin \alpha$ is negative; for $r > 1$ and $\xi > 1$, $\sin \alpha > 0$.

For ready reference we have given in Table I the signs and ranges of R and α for the different regions in the $\xi\eta$ -plane.

Before taking the general case, let us consider how R and α vary along the central line $\eta = 0$. We have now $G = -i/\xi$, hence, we have

$$Re \alpha = \frac{1}{\xi} \left\{1 - \sqrt{1 - \xi^2}\right\}$$

$$\begin{aligned}
 &\text{Now if} \quad \xi < 1, \alpha = 0, R = \frac{1}{\xi} - \left(\frac{1}{\xi^2} - 1 \right)^{\frac{1}{2}} \left. \vphantom{\frac{1}{\xi}} \right\} \quad \dots \quad (2.14) \\
 &\text{but if} \quad \xi > 1, R e^{i\alpha} = \frac{1}{\xi} \left\{ 1 \pm i \left(1 - \frac{1}{\xi^2} \right)^{\frac{1}{2}} \right\} \\
 &\text{Hence} \quad R \cos \alpha = 1/\xi, R \sin \alpha = \pm (1 - 1/\xi^2)^{\frac{1}{2}} \\
 &\text{i.e.} \quad R = 1, \cos \alpha = 1/\xi.
 \end{aligned}$$

This shows that the line $\xi = 1$, divides the $\xi\eta$ -plane in two regions. On the left-hand side, we have $\alpha = 0$ all along the abscissa, up to $\xi = 1$; on the right-hand side $\alpha = \cos^{-1} 1/\xi$ and, therefore, varies from 0 at $\xi = 1$ to $\pi/2$ at $\xi = \infty$. The value of R on the abscissa is $= 1$, if $\xi > 1$ but for $\xi < 1$ it is given by (2.14).

THE $\alpha = \text{CONST.}$ CURVES:

For the N.H. ξ is always positive. The lines $\xi = 1$, and $\eta = 0$ (figs. 1 and 2) divide the plane into four sections (I, II, III, IV) as shown above. We can find out the value of α with the aid of (2.11), and for its sign, we have to look to Table II. (2.11) can also be written as:

$$\frac{(\xi/\lambda^2)^2}{\cos^2 \alpha} - \frac{(\eta/\lambda^2)^2}{\sin^2 \alpha} = 1 \quad \dots \quad (2.15)$$

$$\text{or} \quad \frac{\lambda^2}{2} \sin^2 2\alpha + \cos 2\gamma + \cos 2\alpha = 0 \quad \dots \quad (2.15a)$$

When we wish to draw curve $\alpha = \text{const.}$, we can do so by using (2.11 or 2.15a). A few curves are given in fig. (1, 2). It is seen that for $\alpha > 0$, these curves all cut

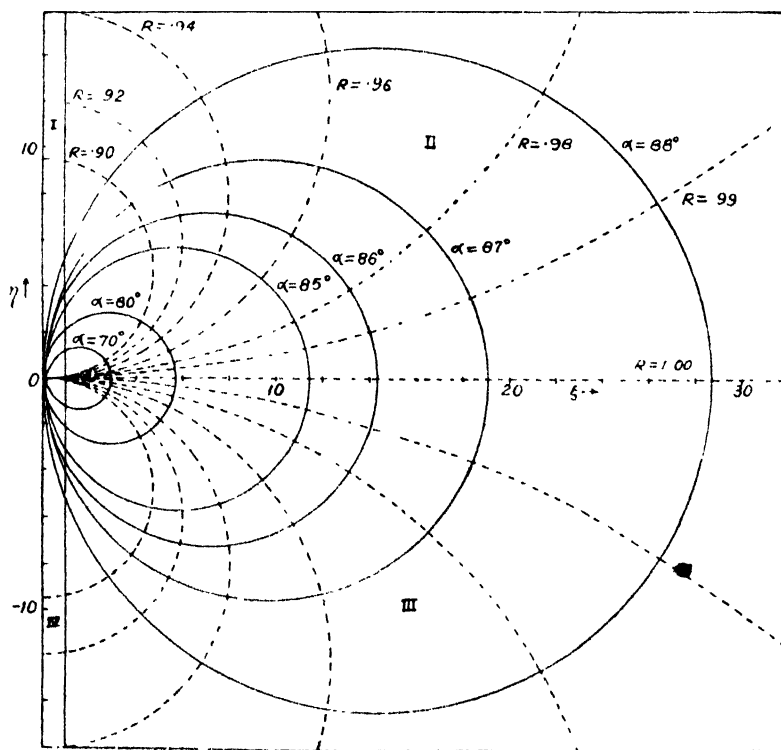


FIG. 1.

the abscissa at right angles at $\xi = \sec \alpha$. The point (0, 0), through which the curve appears to pass is to be excluded, but the curves approach this point at the angle $\pi/2 - \gamma$ to the abscissa.

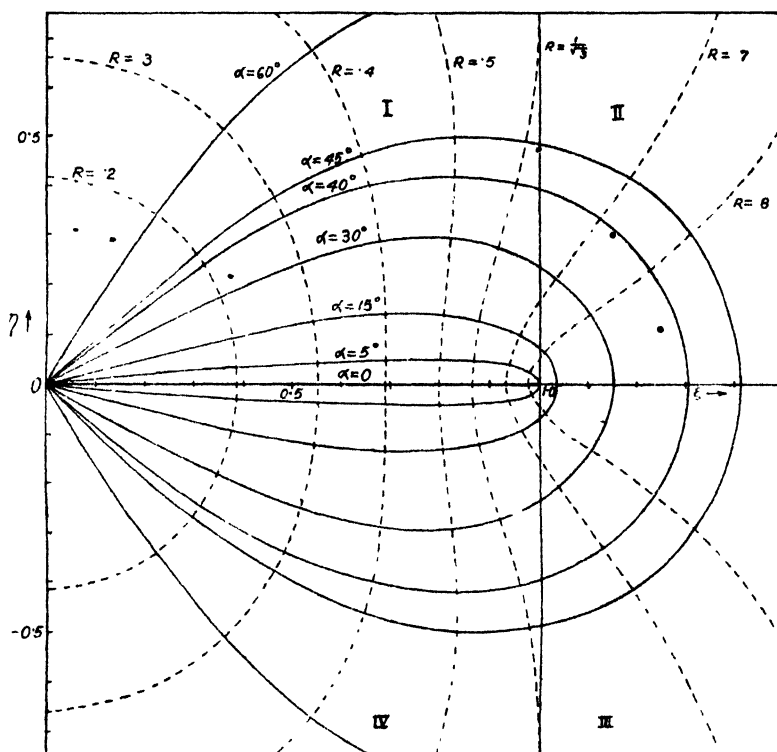


FIG. 2.

The sign of α is positive in sections I, II, III, but is negative in section IV. We have $\alpha = 0$ for the abscissa up to $\xi = 1$; on the ordinate $\alpha = \pi/2$ above the abscissa and $= -\pi/2$ below.

Let us see how to draw the curves $R = \text{const.}$ It can be shown from (2.12) that

$$\left(\frac{\xi}{\lambda^2}\right)^2 / \left(\frac{2R}{1+R^2}\right)^2 + \left(\frac{\eta}{\lambda^2}\right)^2 / \left(\frac{2R}{1-R^2}\right)^2 = 1. \quad \dots \quad (2.16)$$

Now let us put $R = \tan \psi$; then $\sin 2\psi = \frac{2R}{1+R^2}$, $\tan 2\psi = \frac{2R}{1-R^2}$; we can rewrite in the form

$$\lambda^2 = \sin^2 2\psi \{1 + \tan^2 2\psi \cos^2 \gamma\} \quad \dots \quad (2.16a)$$

This gives us the polar equation in the $\xi\eta$ -plane for $R = \text{const.}$ curves; when $R \ll 1$ we have $\sin 2\psi = 2R \ll 1$ and (2.16a) reduces to $\lambda^2 = (2R)^2$, i.e., the $R = \text{const.}$ curves are circles. But as R becomes larger, we have curves as shown in figs. (1, 2). We observe that for $R < 1$, these curves cut the abscissa

($\gamma = \pi/2$) at $\xi = \sin 2\psi = \frac{2R}{1+R^2}$, and the ordinate ($\gamma = 0$) at $\eta = \tan 2\psi = \frac{2R}{1-R^2}$.

The curves crowd as we approach the point $\xi = 1$.

So far the $R = \text{const.}$ curves are confined to sections I and IV. Let us now take sections II and III. From the expression

$$R^2 = (\xi \tan \alpha - \eta) / (\xi \tan \alpha + \eta)$$

We have $R < 1$ in section II, but in Section III we have

$$R^2 = \frac{\xi \tan \alpha + |\eta|}{\xi \tan \alpha - |\eta|} > 1$$

i.e., at the mirror points (ξ, η) , $(\xi, -\eta)$, the values of R are reciprocal to each other. In Section II, $R < 1$, and in section III, $R > 1$.

The $R = \text{constant}$ curves for graded values of R are shown in figs. (1 and 2). In I, II and IV, $R < 1$, while in III R should be read as $1/R$, so that $R > 1$ in this section.

It is to be noticed that for $R < \frac{1}{\sqrt{3}}$ the curves are confined to the left-hand side of $\xi = 1$. The curve $R = \frac{1}{\sqrt{3}}$ touches the line $\xi = 1$, and the curves with $R > \frac{1}{\sqrt{3}}$ cut $\xi = 1$ at two points. For values of $R \simeq 1$, the $R = \text{constant}$ curves are nearly circles with centres at $\left(0, \pm \frac{R}{1-R^2}\right)$ and radius $\frac{R}{1-R^2}$ except very near the point $\xi = 0, \eta = 0$. The family of $R = \text{constant}$ curves cuts orthogonally the family of $\alpha = \text{constant}$ curves.

Scott (1950) has drawn curves similar to those given in figures (1 and 2).

Let us now study the polarisation of the incident and reflected waves in the light of the above discussion. The following table gives the phases for the general and some particular cases, of the eight field quantities E and H for both V and W -waves.

TABLE 1

	Phase Angles	Phase Difference $r = 0, v = 0$	Phase Difference at $\eta = 0$		Phase Difference	
			$|\xi| > 1, \xi > 0$	$|\xi| < 1, \xi > 0$	$|\xi| > 1, \xi < 0$	$|\xi| < 1, \xi < 0$
E_x^V	$\pi - \alpha - \theta_V$	$\pi/2$	$\pi - \sec^{-1} |\xi|$	π	$\sec^{-1} |\xi|$	0
E_y^V	$-\theta_V$	0	0	0	0	0
E_x^W	$\alpha - \theta_W$	$\pi/2$	$\sec^{-1} |\xi|$	0		π
E_y^W	$\pi - \theta_W$	π	π	π	$\pi + \sec^{-1} |\xi|$	π
H_x^V		0			π	
H_y^V		$-\pi/2$				
H_x^W		π				
H_y^W		$+\pi/2$				

The figures in column 2 are obtained from (2.3), (2.4). For others see *infra*.

We have at present no means for determining θ_V and θ_W . For the ground, however, since $r = 0, \delta = 0$ and $\alpha = \pi/2$ for the N.H. we can easily write out the phase differences. They are given in column 3.

We have, therefore, for the ground

$$E_x^V = C_V \cos pt, E_y^V = \frac{C_V}{R} \sin pt, E_x^W = C_W \cos pt, E_y^W = -RC_W \sin pt,$$

$$H_x^V = \frac{C_V}{R} \sin pt, H_y^V = -C_V \cos pt, H_x^W = -RC_W \sin pt, H_y^W = -C_W \cos pt.$$

The value of R can be obtained directly from (2.12) or from the condition $\eta = 2R/(1-R^2)$. We have generally for any point on $\xi = 0$ (no damping),

$$R = \sqrt{1 + 1/\eta^2} - \frac{1}{\eta}$$

and for $r = 0$, we have

$$R = \sqrt{1 + \delta_c^2} - \delta_c.$$

The polarisation-ellipses described by E and H for V and W -waves and their senses of rotation are shown in the figures given below for an assumed value of $R = .6$.

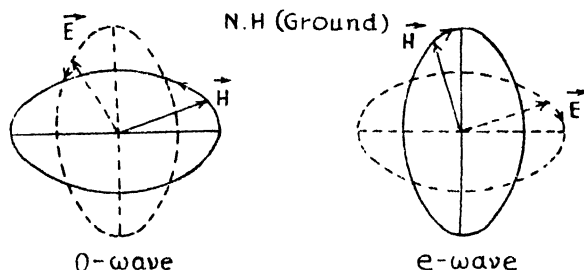


FIG. 3.

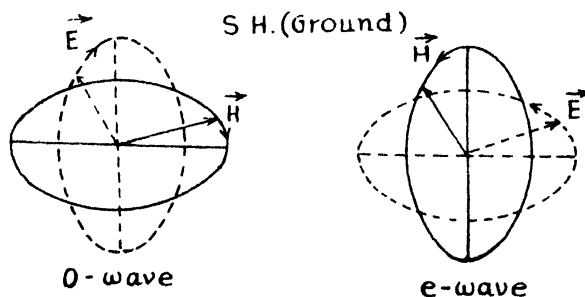


FIG. 4.

It is instructive to see how the polarisation varies with height. For $r = 1$ we can easily deduce the values of the relative phase angles for E with the aid of the above relations which are given in columns 4 and 5 of Table I. We have not given phase-angles for H , as relation (1.24) then no longer holds. We have now for $\xi = \infty, r = 1$.

$$E_x^V = C_V \cos pt, E_y^V = C_V \sin pt; E_x^W = C_W \cos pt, E_y^W = -C_W \sin pt$$

These are circles as shown in fig. 5(e).

For $\xi > 1$, $r = 1$, putting $\alpha = \cos^{-1} \frac{1}{\xi}$

$$E_x^V = -\frac{C_V}{\sqrt{1-1/\xi^2}} \sin(pt-\alpha), \quad E_y^V = \frac{C_V}{\sqrt{1-1/\xi^2}} \sin pt;$$

$$E_x^W = \frac{C_W}{\sqrt{1-1/\xi^2}} \sin(pt+\alpha), \quad E_y^W = -\frac{C_W}{\sqrt{1-1/\xi^2}} \sin pt.$$

These are ellipses, circumscribed within a square as shown in fig. 5(d), the contact points being given by (2.17a) and the ratio of axes are $\sqrt{(\xi-1)/(\xi+1)}$, the angle of tilt being $\pi/4$. For $\xi = 1$, $r = 1$,

$$E_x^V \simeq -\sin pt, \quad E_y^V \simeq \sin pt, \quad E_x^W \simeq \sin pt, \quad E_y^W \simeq -\sin pt$$

The ellipse reduces to a straight line coincident with the diagonal of the square. For $\xi < 1$, $r = 1$.

$$E_x^V = -\sin pt, \quad E_y^V = R^{-1} \sin pt, \quad E_x^W \simeq \sin pt, \quad E_y^W = R \sin pt$$

This is shown in fig. 5(c).

For $\xi > 1$, the curves are lines forming diagonals of two oblongs as shown in fig. 5(b), the ratio of the sides of the oblongs being given by R or R^{-1} .

When $\xi = 0$, $r = 1$, we have $R = 0$, $R^{-1} = \infty$ and the polarisation ellipses reduce to two straight lines parallel to the magnetic axis and perpendicular to it (Fig. 5(a).)

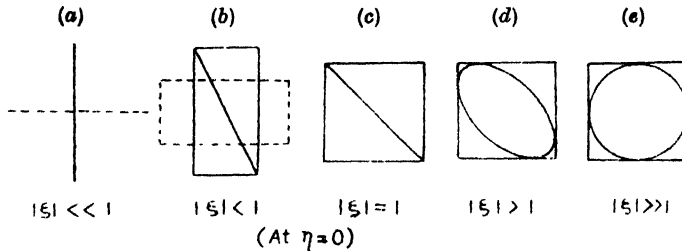


FIG. 5.

Figures of polarisation ellipses for $r = 1$ have been given by Booker (1934) for the magnetic vector. It will be seen that the diagonal lines in our figures are in the first and third quadrants. This is because we have drawn polarisation ellipses for E , while Booker has drawn for H .

In general, omitting θ_V and θ_W we have for any point of the ionosphere where R and α have the values given in Table II

$$E_x^V = -\frac{C_V}{\sin \alpha} \sin(pt-\alpha), \quad E_y^V = \frac{C_V}{R \sin \alpha} \sin pt,$$

$$E_x^W = \frac{C_W}{\sin \alpha} \sin(pt+\alpha), \quad E_y^W = -\frac{RC_W}{\sin \alpha} \sin pt.$$

Now eliminating pt we deduce the following equations for the ellipses described by E_x and E_y :

$$\left. \begin{aligned} (E_x^V)^2 + 2R \cos \alpha \cdot E_x^V E_y^V + R^2 (E_y^V)^2 &= C_V^2 \\ (E_x^W)^2 + 2R^{-1} \cos \alpha \cdot E_x^W E_y^W + R^{-2} (E_y^W)^2 &= C_W^2 \end{aligned} \right\} \quad (2.17)$$

TABLE II.

$\xi = \frac{\delta}{\delta_c}$	$\eta = \frac{1-r}{\delta_c}$	$i\rho = Re^{i\alpha}$		Polarisation of the electric vector	
		R	α	Nature of polarisation	Sense of rotation
$|\xi| = 0, \delta = 0$	$\eta > 0$	$\frac{\sqrt{1+\eta^2}}{|\eta|}$	$+\frac{\pi}{2}$	Ellipse; ratio of axes = R ; Tilt-angle = 0 (o-wave and e-wave)	Anticlockwise for o-wave and Clockwise for e-wave
	$\eta < 0$	Do.	$-\frac{\pi}{2}$	Do.	Clockwise for o-wave and anticlockwise for e-wave
$|\xi| < 1$	$\eta = 0, (r = 1)$	$\frac{1-\sqrt{1-\xi^2}}{|\xi|}$	0 for $\xi > 0$, π for $\xi < 0$	Linear, tilt-angle $\tan^{-1}(-R)$ and $\tan^{-1}\left(\frac{1}{R}\right)$ for two waves	
$|\xi| = 1$	$\eta = 0, (r = 1)$	1	Do.	Linear, tilt-angle $-\pi/4$ and $+\pi/4$.	
$|\xi| > 1$	$\eta = 0, (r = 1)$	1	$\sec^{-1}|\xi|$, 1st Quadrant for $\xi > 0$, 3rd for $\xi < 0$	Ellipse, ratio of axes = $\sqrt{\frac{|\xi|-1}{|\xi|+1}}$ Tilt-angle $-\pi/4$ and $+\pi/4$	Anticlockwise for o-wave and Clockwise for e-wave
$\xi > 0, (N.H.)$	$\eta > 0, |\xi| < 1$	$R < 1$	$0 < \alpha < \pi/2$	Ellipse, defined by eqn. (2.17)	Anticlockwise for o-wave and Clockwise for e-wave
	$|\xi| > 1$	$R < 1$	$0 < \alpha < \pi/2$	Do.	Do.
	$|\xi| < 1$	$R < 1$	$-\pi/2 < \alpha < 0$	Do.	Clockwise for o-wave and Anticlockwise for e-wave
	$\eta < 0, |\xi| > 1$	$R > 1$	$0 < \alpha < \pi/2$	Do.	Do.
$\xi < 0, (S.H.)$	$|\xi| < 1$	$R < 1$	$\pi/2 < \alpha < \pi$	Do.	Do.
	$\eta > 0, |\xi| > 1$	$R > 1$	$\pi < \alpha < 3\pi/2$	Do.	Do.
	$|\xi| < 1$	$R < 1$	$\pi < \alpha < 3\pi/2$	Do.	Anticlockwise for o-wave and Clockwise for e-wave
	$\eta < 0, |\xi| > 1$	$R < 1$	$\pi < \alpha < 3\pi/2$	Do.	Do.
$|\xi| = 0, \delta_c = \infty, \delta \neq 0$ (Equator)	$\eta > 0, (+\infty)$	0	$\tan^{-1}\frac{(1-r)}{\delta}$ $\rightarrow 0$ for N.H. and π for S.H. as $\gamma \rightarrow 1$	Linear polarisation, Tilt = 0	
	$\eta < 0, (-\infty)$	0	Do.	Linear polarisation, Tilt = 0	
$|\xi| = \infty, \delta_c = 0, \delta \neq \infty$ (Pole)	$\eta < 0$	1	$+\pi/2$	Circular polarisation	Anticlockwise for o-wave and Clockwise for e-wave
	$\eta < 0$	1	$-\pi/2$	Do.	Clockwise for o-wave and Anticlockwise for e-wave
Ground, (N.H.)		$\sqrt{1+\delta_c^2} - |\delta_c|$		Ellipses, given by equation (2.17)	Sense of rotation Shown in figs. (3) and (4)
Ground, (S.H.)		Do		Do.	Do.

The axes of the polarisation ellipses are tilted with respect to x -axis through the angle ψ given by

$$\tan 2\psi^V = \frac{2R \cos \alpha}{1-R^2}, \quad \tan 2\psi^W = -\frac{2R \cos \alpha}{1-R^2}.$$

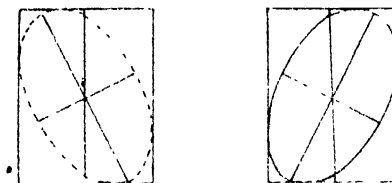


FIG. 6.

It is easy to see that $\psi^V = \left(n + \frac{1}{2}\right)\pi - \psi^W$. These ellipses can be shown to be inscribed within oblongs having the sides

$$\left(\pm \frac{C}{\sin \alpha}\right), \quad \left(\pm \frac{C}{R \sin \alpha}\right)$$

and touching the sides at the points

$$(\pm C_{V,W}/\sin \alpha), \quad (\mp C_{V,W} \cot \alpha/R); \quad (\pm C_{V,W} \cot \alpha), \quad \left(\mp C_{V,W} \frac{\sin \alpha}{R}\right). \quad (2.17a)$$

The ratio of the axes is given by

$$\frac{(1+R^2) + \sqrt{(1+R^2)^2 - 4R^2 \sin^2 \alpha}}{(1+R^2) - \sqrt{(1+R^2)^2 - 4R^2 \sin^2 \alpha}}.$$

From these general expressions we can obtain the shape and sense of rotation of the polarisation ellipse at any point inside the ionosphere. We have described the nature of polarisation of the electric vector for any value of ξ , η in the last column of Table II.

§ 3. THE COUPLING TERM.

Let us now turn to the application of these formulæ to actual cases. For these, we require the characteristics of ionospheric stations. These are given in Table III for a number of stations between the geomagnetic equator and N.M.P.

The second row gives the propagation angle θ of the stations given in the first row, and the other rows are self-explanatory. As we see from row 6, the value of ν_c , the magnetic damping factor varies from ∞ at the equator, to zero at the pole, passing through a value of $75 \times 10^6/\text{sec.}$ at the ionospheric station nearest to the G.M.-equator, to $5.5 \times 10^4/\text{sec.}$ at the Clyde River station which is nearest to the N.M.P.

The values of all ionospheric quantities R , α , ϕ , q_0^2 , q_s^2 are functions of ξ and η . Now $\xi = \nu/\nu_c$ and is independent of p . The collision frequency in any ionospheric layer is taken to vary as $\nu = \nu_0 \exp\left\{-\frac{z-z_0}{l}\right\}$, where l is the scale height, ν_0 is the value of the collision frequency at the tip of the layer, z_0 is the height of

TABLE III.

	Equator	Huancayo	Calcutta	Slough	Kiruna	Clyde River	North Pole
θ	90°	92°	112°	157°	167°	174°	180°
$\frac{\rightarrow}{|H|}$		.296 Γ	.434 Γ	.470 Γ	.514 Γ	.570 Γ	
$f_h = \left| \frac{cH}{2\pi mc} \right|$		.829,10 ⁶	1.222,10 ⁶	1.316,10 ⁶	1.439,10 ⁶	1.596,10 ⁶	
$\Omega = \left| \frac{\sin^2 \theta}{2 \cos \theta} \right $	∞	14.31	1.148	.083	.026	.005	0
$|\nu_c| = 2\pi f_h \Omega$	∞	74.50,10 ⁶	8.79,10 ⁶	.686,10 ⁶	.235,10 ⁶	.055,10 ⁶	0
$\nu = 2 \cdot 10^6$	0	.269,10 ⁻²	2.27,10 ⁻²	29.2,10 ⁻²	84.8,10 ⁻²	364,10 ⁻²	∞
$|\xi| = \frac{\nu}{|\nu_c|}$							
$\nu = 10^3$	0	.134,10 ⁻⁴	1.14,10 ⁻⁴	14.6,10 ⁻⁴	42.6,10 ⁻⁴	182,10 ⁻⁴	∞
$\nu = 2.10^5$ $l = 10 \text{ km}$	0	.200,10 ⁻³	1.71,10 ⁻³	23.9,10 ⁻³	227,10 ⁻³	22.7,10 ⁻³	∞
$|\phi_{\max}|$ $\nu = 10^3$ $l = 50 \text{ km}$	0	.040,10 ⁻³	.341,10 ⁻³	4.37,10 ⁻³	12.8,10 ⁻³	55.6,10 ⁻³	∞

the tip of the layer. The values of ν_0 , z_0 vary with the hour of the day, the season and other factors. We have taken

$$\begin{aligned}\nu_0 &\simeq 2.10^5/\text{sec. for the } E\text{-layer.} \\ &\simeq 10^3/\text{sec. for the } F\text{-layer.}\end{aligned}$$

as good average values for ν_0

The corresponding values of ξ_0 are given in rows (7) and (8) for the E and F -layers.

We observe that for the F -layer, ξ_0 varies from $\simeq 10^{-4}$ at Huancayo to 1.8×10^{-2} at Clyde River. We can therefore take $\xi < 1$ for F -layer propagation. At the G.M.E. $\xi = 0$, and at the pole $\xi = \infty$. These points require separate treatment. For the treatment of wave propagation through F -layer, we have therefore to confine ourselves to sections I and IV of the $\xi\eta$ -plane.

For the E -layer, ξ_0 continues to be small for low latitude stations, but at Slough it has attained the value .29 and at times may approach unity. For the higher latitude stations, e.g. Clyde River $\xi_0 \simeq 3.63$

PATH OF THE RAY IN THE $\xi\eta$ -PLANE.

The vertical propagation of a ray in the $\xi\eta$ -plane can be shown by a trajectory. We have

$$\xi = \xi_0 \exp \left\{ -\frac{z-z_0}{l} \right\} \quad \dots \quad (3.1a)$$

and

$$\eta = \frac{1}{\delta_c} (1 - \tau_0 \gamma)$$

where $r_0 = \frac{4\pi N_0 e^2}{m p^2} = p_c^2/p^2$ and $\gamma = \exp \frac{1}{2} \left[1 - \frac{z-z_0}{l} - e^{-(z-z_0)/l} \right]$.. (3.1b)

is the Chapman Factor.

N_0 is the maximum concentration of ions in the layer.

Let us now consider the coupling coefficient $\dot{\phi}$. It can be easily shown that

$$\dot{\phi} = \tan^{-1}(\rho) = \frac{1}{2} \cdot \frac{\dot{\eta} - i\dot{\xi}}{(1 - \xi^2 + \eta^2) - 2i\eta\xi} \quad \dots \quad (3.2)$$

We obtain after some work.

$$R_e(\dot{\phi}) = \frac{1}{2} \cdot \frac{(1 - \xi^2 + \eta^2)\dot{\eta} + 2\eta\xi\dot{\xi}}{(1 - \xi^2 + \eta^2)^2 + 4\eta^2\xi^2} \quad \dots \quad (3.3a)$$

$$I_m(\dot{\phi}) = -\frac{1}{2} \cdot \frac{(1 - \xi^2 + \eta^2)\dot{\xi} - 2\eta\eta\dot{\xi}}{(1 - \xi^2 + \eta^2)^2 + 4\eta^2\xi^2} \quad \dots \quad (3.3b)$$

$$|\dot{\phi}| = \frac{1}{2} \left[\frac{\dot{\eta}^2 + \dot{\xi}^2}{(1 - \xi^2 + \eta^2)^2 + 4\eta^2\xi^2} \right]^{\frac{1}{2}} \quad \dots \quad (3.3c)$$

Let us now find out values of $\dot{\eta}$ and $\dot{\xi}$. With the assumptions made in this section, i.e. $\nu = \nu_0 \exp. [-(z-z_0)/l]$ it can be easily shown that

$$\dot{\xi} = \frac{d\xi}{du} = -\frac{c}{p} \frac{\xi}{l}$$

Similarly it can be shown, assuming that N is given by a Chapman-layer, that

$$\eta = \frac{cr}{p\delta_c l} \beta = \frac{c}{pl} \beta \left(\frac{1}{\delta_c} - \eta \right)$$

where

$$\beta = \frac{1}{2} \left(1 - e^{-(z-z_0)/l} \right)$$

We have therefore

$$R_e(\dot{\phi}) = \frac{c}{2pl} \cdot \frac{(1 + \eta^2 - \xi^2)\beta \left(\frac{1}{\delta_c} - \eta \right) - 2\eta\xi^2}{(1 + \eta^2 - \xi^2)^2 + 4\eta^2\xi^2} \quad \dots \quad (3.4a)$$

$$I_m(\dot{\phi}) = \frac{c}{2pl} \cdot \frac{(1 - \xi^2 + \eta^2)\xi + 2\eta\xi\beta \left(\frac{1}{\delta_c} - \eta \right)}{(1 + \eta^2 - \xi^2)^2 + 4\eta^2\xi^2} \quad \dots \quad (3.4b)$$

$$|\dot{\phi}| = \frac{c}{2pl} \cdot \left[\frac{\beta^2 \left(\frac{1}{\delta_c} - \eta \right)^2 + \xi^2}{(1 + \eta^2 - \xi^2)^2 + 4\eta^2\xi^2} \right]^{\frac{1}{2}} \quad \dots \quad (3.4c)$$

From the above expression for $|\dot{\phi}|$ it is seen that this attains its maximum value at $\eta = 0$. We have then

$$|\dot{\phi}_{\max}| = \frac{c}{2pl} \cdot \left[\frac{\beta^2/\delta_c^2 + \xi^2}{(1 - \xi^2)^2} \right]^{\frac{1}{2}} \quad \dots \quad (3.5)$$

Therefore $|\dot{\phi}_{\max}|$ is very large for $\xi \simeq 1$ and tends to infinity as $\xi \rightarrow 1$.

When a wave of any frequency travels through a layer we observe that to every point of the layer there correspond definite values of ξ and η ; we can therefore

plot on the $\xi\eta$ -plane a series of points corresponding to different values of z . The curves joining these points may be called the trajectory of the wave in the $\xi\eta$ -plane. Such a trajectory drawn for Slough is shown in fig. 7. The points ξ

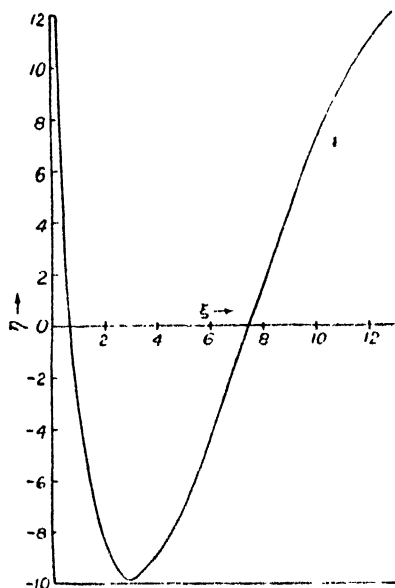


FIG. 7.

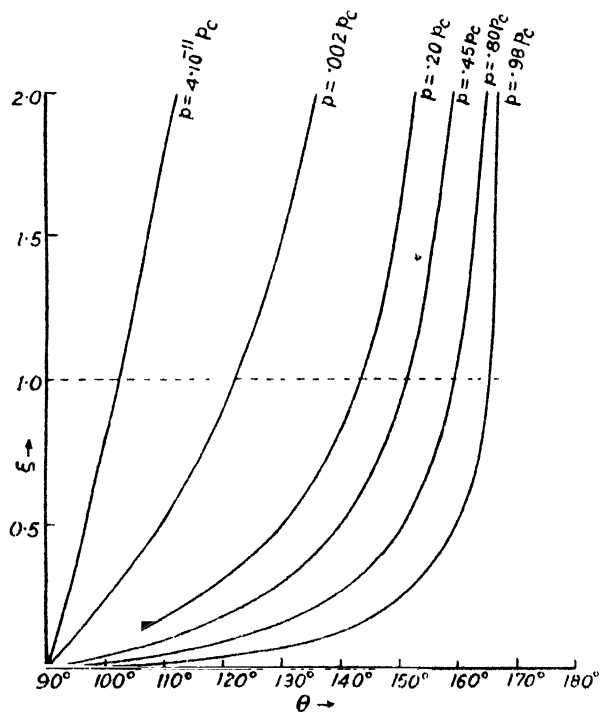


FIG. 8.

and η have been calculated on the assumption that the variation of collision frequency is given by (3.1a) and the electron concentration is given by (3.1b). As we are interested in the maximum value of ϕ , we require the value of ξ at $\eta = 0$ on the trajectory of the wave in the $\xi\eta$ -plane. This value of ξ depends on the frequency of the wave and the location of the station. Fig. 8 gives a number of (ξ, θ) curves (at $\eta = 0$) for different values of p/p_c . The layer has been assumed to be the E -layer with $\nu_0 = 2.10^5/\text{sec}$. The corresponding values of ξ for an F -layer with $\nu_0 = 10^3/\text{sec}$. will simply be 1/200th of the values given by the curves. Certain conclusions can be immediately reached from the nature of these curves.

TABLE OF NOTATIONS

Quantity	Saha <i>et al.</i>	Appleton <i>et al.</i>	Hartree	Eckersley	Rydbeck
Direction of Propagation ..	z	z	..	z	z
Horizontal in Magnetic Meridian ..	x	x	..	x	y
Horizontal \perp to Magnetic Meridian ..	y	y	..	y	x
Propagation Angle ..	θ	..	..	..	θ_p
Field Vectors ..	E, H, P, I	E, H, P, I	E, H, I	E, P	E, I, P
Earth's Magnetic Field ..	H	H	H	H	H
Refractive Index ..	μ	μ	μ	μ	μ
Complex Refractive Index ..	$q = \mu - i\kappa/p$	cq	K	Z	$\sqrt{\epsilon}$
Absorption Coefficient ..	K	K	..	..	..
Pulsatance ..	p	p	kc	$2\pi\nu$	ω
Gyropulsatance $\frac{eH}{mc}$..	p_h	p_h	$k_h c$	$2\pi\nu_H$	ω_H
Frequency ..	f	f	$kc/2\pi$	ν	$\omega/2\pi$
Gyrofrequency ..	f_h	f_h	$k_h c/2\pi$	ν_H	$\omega_H/2\pi$
Collision Frequency ..	ν	ν	$2k_f c$	ν_c	ν
Relative Gyrofrequency $f_h/f = p_h/p$..	ω	$-\gamma/\alpha, y$	τ	τ	γ/x_0^2
Relative Collision Frequency ν/p ..	δ$	..	..	\alpha_c/2\pi$	δ
Phase Velocity ..	v	v	..	..	..
Group Velocity ..	w	u	..	..	..
Displacement of the Ion ..	$\vec{S}(\xi, \eta, \zeta)$	x, y, z	\vec{P}	..	..
Dipole Moment ..	\vec{NeS}	$Ne(x, y, z)$	\vec{NeP}	..	..
Scattering Tensor ..	$\frac{\gamma\Delta}{\beta(\beta^2 - \omega^2)}$	..	σ	$-\alpha$	..
Ratio of Axes ..	ρ	R	..	..	u
Critical Pulsatance $\frac{4\pi Ne^2}{m}$..	p_0^2	P_0^2	..	$4\pi^2\nu_0^2$	ω_c^2
$4\pi Ne^2/mp^2 = p_0^2/p^2$..	r	$-\frac{1}{\alpha}, x$	σ_0	ζ	$\frac{1}{r_0^2}$
$\frac{eH}{mcp}/[1 - i\nu/p]$..	$-\omega/\beta$	..	$K\alpha H$	ν_H/ν'	..
$\frac{4\pi Ne^2}{mp^2}/[1 - i\nu/p][1 - p_h^2/p^2(1 - i\nu/p)^2]$..	$-4\pi A/\beta^2$	$\frac{\alpha}{\alpha^2 - \gamma^2}$	ξ	ζ	..
$\frac{4\pi Ne^2}{mp^2}/[1 - i\nu/p]$..	r/β	$\frac{1}{\alpha + \alpha}$	σ_0	..	..
$mp\nu/4\pi Ne^2$..	δ/r	β	..	..	..
$\frac{mp}{4\pi Ne^2} \left[\frac{eH}{mc} \right]$..	$\frac{\omega}{\tau}$	γ	P/σ_0	..	γ

The frequency at which the point ($\xi = 1$, $\eta = 0$) is crossed depends on the magnetic characteristics of the station and the relation is given as

$$p = p_c(\nu_c/\nu_0)^{\frac{1}{2}}e^{-\frac{1}{2}\nu_c/\nu_0}$$

For stations where the magnetic damping is large compared to the collisional damping (equatorial region) this point is reached when $p < p_c$, while for high latitude stations $\nu_c < \nu_0$ and this critical value of p approaches p_c . For F -layer propagation, since $\nu_c \gg 1$ practically over the entire globe (excepting the small polar belt), it follows that the critical point ($\xi = 1$, $\eta = 0$) will be reached when $p < p_c$, i.e. when the wave will fail to reach F -layer owing to the presence of the lower E -layer.

Only when $\nu_c/\nu_0 \simeq 1$ cases of practical importance will arise. Ionospheric stations like Kiruna and Slough are therefore suitable for observations of any peculiarities arising out of this coupling term. In such cases $|\dot{\phi}|_{\max}$ will be quite large and the approximate differential equations will no longer be valid. Though this does not necessarily imply that the large $|\dot{\phi}|$ is solely responsible for the triple splitting, as has been suggested by Rydbeck, it cannot be denied that the nature of propagation may be profoundly modified. As no one has yet been able to give an exact treatment of the differential equations, it is not safe to make any definite statement about the nature of this modification.

ACKNOWLEDGMENT.

B. K. Banerjea wishes to record his thanks to the National Institute of Sciences for the award of a Fellowship. U. C. Guha wishes to record his thanks to the Council of Scientific and Industrial Research for the award of a scholarship.

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THE EFFECTIVENESS OF GONADOTROPIC HORMONE THERAPY IN PREVENTION OF TESTICULAR ATROPHY IN THE PIGEON CAUSED BY ADRENALIN

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INTRODUCTION

During the past quarter of a century evidence of a relationship between the adrenal medulla and the gonads has been accumulating. Eaton *et al.* (1929) reported that when chicks were fed 0.5 grains of adrenal medulla daily from the 12th to 89th day of life the testes of the control birds weighed 37 per cent heavier than those of the medulla-fed males. Riddle and Minoura (1923) transplanted whole adrenal glands into ring doves and found that the testes of the birds receiving the transplants were significantly smaller than those of the controls. Eguchi (1927) observed that repeated subcutaneous injections of adrenalin caused testicular atrophy in the rabbit and the guinea-pig. This atrophy was characterized by the marked degeneration of the interstitial cells and the inhibition of spermatogenesis. Perry (1941 *a*) noted that 15 to 20 one-half minim doses of adrenalin (1:1000) daily injected into the pectoral muscles of male and female English sparrows, caused a regression of the gonads, accessories and secondary sexual characters to the juvenile condition. Perry (1941 *b*) extended this study to the rat and found that experimental hyperadrenalism resulted in the degeneration of the testes and atrophy of the various accessories. Wheeler *et al.* (1942) demonstrated that the administration of adrenalin in the fowl was followed by atrophy of the seminiferous tubules and the marked decrease in semen volume.

From the works cited above it is evident that adrenalin is a substance which is undoubtedly antagonistic to gonadal function. Unfortunately, no attempt has so far been made to find out an effective hormone therapy which would prevent the harmful gonadal changes caused by experimental hyperadrenalism. The present report is the outcome of an effort to test the effectiveness of gonadotropic hormone in prevention of adrenalin-induced changes in the testes of adult pigeons.

EXPERIMENTAL RESULTS

Adult male pigeons were used in this study. A total of 15 birds were involved of which 5 were injected with adrenalin, 5 with adrenalin plus gonadotropic hormone, and the remaining 5 were left uninjected to serve as the controls. The birds were housed in cages and maintained under uniform husbandry conditions throughout the duration of the experimental period. The initial body weight of each bird was taken at the commencement of the experiment, and the final weight was recorded on the day of autopsy.

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Liq. Adrenalin Tartratis (Standard Pharmaceutical Works, Calcutta), 1:1000 dilution, was administered intramuscularly to one group of pigeons. The daily injections (2 minim) were made into the pectoral muscles and continued for a period of 8 days. An equal amount of this drug (2 minim daily) was injected in the similar manner and over the same period of time to a second group of birds. In addition to adrenalin this group also received four injections of 'Geetyl' (Organon Laboratories), each containing 100 I.U. of serum gonadotropin. The gonadotropic hormone therapy started simultaneously on the second day of adrenalin treatment and was continued on every alternate days till the 8th day, 24 hours subsequent to which all the birds were autopsied.

The testes were carefully dissected out, weighed to the nearest mgm., and finally fixed in alcoholic Bouin's fluid for histological studies. Serial sections of the testes were prepared by the paraffin method and stained with Heidenhain's iron-alum hematoxylin.

RESULTS

Controls.—The absolute and relative weights of the testis are presented in Table 1. Histologically, the picture presented is typical of a mature testis at its height of spermatogenetic activity. This can be observed from the presence of large seminiferous tubules and the marked activity of the cellular elements contained therein. The successive stages of transformation of the seminiferous epithelium into spermatogonia, spermatocytes, spermatids, and spermatozoa can clearly be seen in the tubules (Pl. VI, fig. 1). The cellular divisional figures are very prominently visible in the tubular elements.

The interstitium is greatly obliterated owing to the marked activity of the seminiferous tubules. However, at certain locations clumps of Leydig cells are very clearly distinguishable in the connective tissue matrix of the interstitium. The fibroblasts are prominent by their absence. A rich vascularity is also evident in the interstitium.

TABLE 1

Testicular weights in control and treated pigeons

	Number of birds	Testicular weight		Body weight at autopsy
		Absolute	Relative*	
		Mgm.	Per cent	Gm.
Controls ..	5	250.0	0.09	293.0
Adrenalin treated ..	5	110.0	0.03	286.2
Adrenalin plus Gonadotropic hormone treated ..	5	300.0	0.1	273.7

* Testis weight expressed as percentage of body weight.

Adrenalin treatment.—Macroscopic examination reveals a marked inhibitory effect on testicular size. This is unmistakably reflected in the significant loss of testis weight of the treated birds (Table 1). Microscopically, the testis presents an atrophic condition. The seminiferous tubules appear small and shrunken. The spermatogenesis has not progressed beyond the stage of spermatogonia formation. Even the cellular elements of the tubules show various stages of pycnosis of the nucleus and the degeneration of the cytoplasm. In extreme cases the tubular lumen appears to be filled with degenerated remnants of these elements (Pl. IV,

fig. 2). The picture is comparable to a similar one which is encountered in the testicular tubules of this species after androgen treatment (Kar, 1949).

The interstitium shows a definite loss of vascularity and a marked increase in the number of fibroblasts over the Leydig cells. The latter appear shrunken and degenerated like the seminiferous epithelial elements.

Gonadotropic hormone therapy.—Gross examinations at autopsy shows that the inhibitory effect of adrenalin on the testicular size is definitely obviated by gonadotropic hormone. Data on testis weight presented in Table 1 confirm this macroscopic findings and undoubtedly indicate the preventive action of hormone therapy on the testis of adrenalin-treated birds. The final confirmation of the effect of gonadotropic hormone however, comes from a careful evaluation of the histological data. The seminiferous tubules show full activity and the various stages of spermatogenesis are prominently displayed in the sections (Pl. VI, fig. 3).

The interstitium appears hyperemic and the only cellular elements distinguishable are the Leydig cells. The number of fibroblasts are reduced to the minimum. All these features added together prove that the organ has retained its normal functioning order comparable to that of the testis of the control birds.

DISCUSSION

The results of this study tend to bear out the findings made by several previous investigators (Eaton *et al.*, 1929; Riddle and Minoura, 1923; Eguchi, 1927; Perry, 1941 *a* and *b*; and Wheeler *et al.*, 1942) that adrenalin produces atrophic changes in the testis. Further, the therapeutic part of this experiment demonstrates very clearly that the gonadotropic hormone is quite effective in preventing the testicular changes caused by adrenalin.

A question may now be raised concerning the possible mechanism responsible for this apparent adrenalin-gonad antagonism. The sensitivity of the testis to many specific substances and to unbalanced physiological condition is well known (Turner, 1948) and so caution must be exercised in drawing conclusions as to the mode of action of adrenalin in testicular atrophy. However, Perry (1941 *a*) reports that gonad inhibition in the English sparrow following adrenalin injections is probably the result of decreased secretion, release or activity of the anterior pituitary gonadotropin. In the rat (Perry, 1941 *b*) there is considerable variation in the testicular damage which follows adrenalin administration, and the interruption of spermatogenesis is most marked in rats which are treated during the summer months. Perry concludes that the mode of action in the rat differs from that in the sparrow and suggests that the calorogenic effect of adrenalin in conjunction with the high environmental temperatures of the summer months may have been partially responsible for the inhibition of spermatogenesis.

The prevention of testicular atrophy of the adrenalin-treated pigeons by gonadotropic hormone therapy is an item of considerable significance. This finding suggests that the gonadotropic activity of the anterior pituitary is markedly inhibited by the injection of adrenalin and that the testicular changes are probably the secondary effects of this hypophyseal inhibition. The simultaneous injection of exogenous gonadotropic hormone appear to obviate this inhibitory action of adrenalin on the pituitary gonadotropic activity, and this is clearly reflected in the continuation of spermatogenesis in the testis of adrenalin-treated birds. The final substantiation of this concept however, would appear to come from a comparative study of the gonadotropin content of the hypophysis of normal, adrenalin-treated, and adrenalin plus gonadotropic hormone-treated birds. This problem, unfortunately, does not fall within the purview of the present investigation, but is undoubtedly one which is worthy of a future study.

SUMMARY

Intramuscular injections of adrenalin into adult pigeons cause extensive damage to the testicular tissues. Gonadotropic hormone therapy in adrenalin-treated birds prevents testicular atrophy. The possible mechanism responsible for this apparent adrenal-gonad antagonism is discussed.

ACKNOWLEDGMENTS

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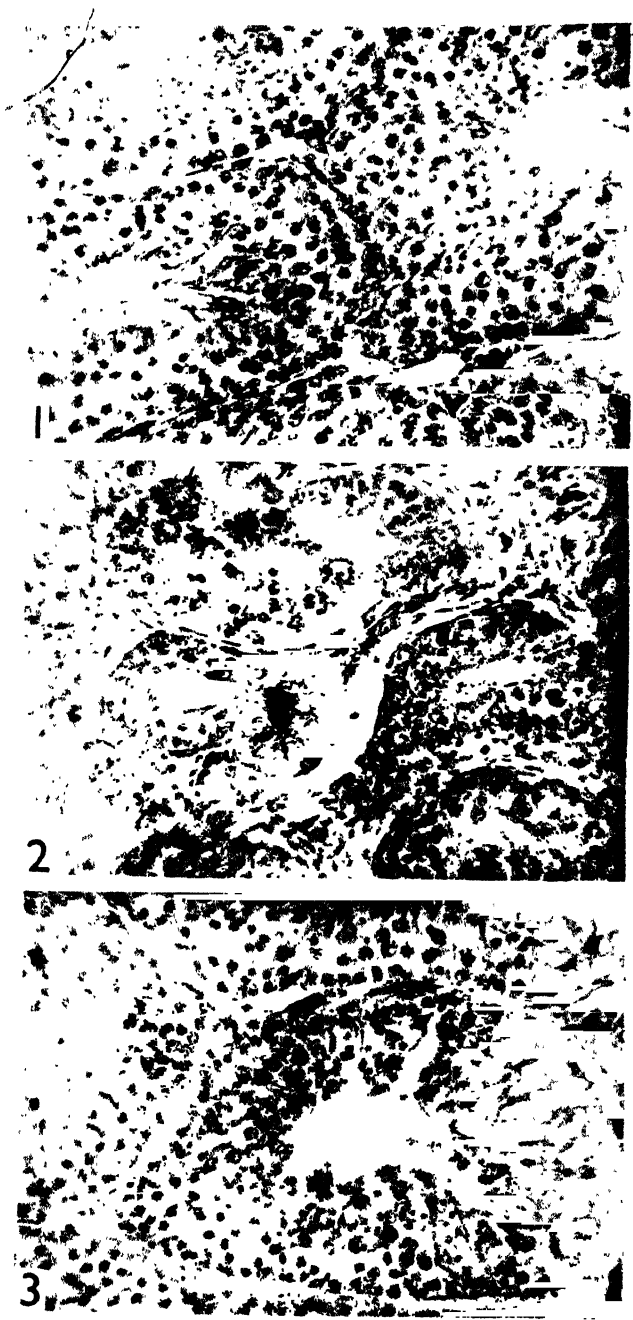
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EXPLANATION OF PLATE VI.

(All figures are photomicrographs and are magnified $\times 130$)

- FIG. 1. Section through the testis of a control pigeon. Note the various stages of spermatogenesis.
- FIG. 2. Section through the testis of an adrenalin-treated pigeon. Note the atrophic condition of the testicular tissues.
- FIG. 3. Section through the testis of an adrenalin plus gonadotropic hormone treated pigeon. Note the continuation of spermatogenesis.



A GENERALIZATION OF THE PARTITION FUNCTION*

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1. We define $v_r(n)$ by the relation

$$nv_r(n) = \sum_{j=1}^n \sigma_r(j) v_r(n-j), \quad n \geq 1; \quad \dots \quad \dots \quad \dots \quad (1)$$

where $\sigma_r(j)$ denotes the sum of the r th powers of the divisors of j and $v_r(0) = 1$.

It would be readily seen that $v_1(n)$ is nothing but the function $p(n)$ denoting the number of unrestricted partitions of n .

We proceed to show that $v_r(n)$ is the coefficient of x^n in the expansion of

$$J(x) = \prod_{j=1}^{\infty} (1-x^j)^{-j^{r-1}}, \quad |x| < 1. \quad \dots \quad \dots \quad \dots \quad (2)$$

Let

$$J(x) = \sum_{t=0}^{\infty} u_t x^t, \quad u_0 = 1.$$

Differentiating (2) logarithmically with respect to x , we obtain

$$\begin{aligned} \sum_{t=0}^{\infty} t u_t x^t \cdot \sum_{t=0}^{\infty} u_t x^t &= x J'(x) \cdot J(x), \\ &= \left\{ \frac{1^r x}{1-x} + \frac{2^r x^2}{1-x^2} + \frac{3^r x^3}{1-x^3} + \dots \right\} \\ &= \sum_{j=1}^{\infty} \sigma_r(j) x^j \end{aligned}$$

or

$$\sum_{t=0}^{\infty} t u_t x^t = \sum_{t=0}^{\infty} u_t x^t \cdot \sum_{j=1}^{\infty} \sigma_r(j) x^j. \quad \dots \quad \dots \quad \dots \quad (3)$$

Equating the coefficients of x^n on the two sides of (3), we get

$$n u_n = \sum_{j=1}^n \sigma_r(j) u_{n-j}, \quad n \geq j.$$

Since this relation is the same as (1), we must have

$$u_n = v_r(n).$$

From (2), it would be readily seen that $v_r(n)$ is the number of partitions of n when element k is of k^{r-1} different types, i.e. when there are 2^{r-1} different two's, 3^{r-1} different three's and so on.

* Suggested by Dr. D. S. Kothari.

2. If we now define $v_r(n, m)$ by the relation

$$nv_r(n, m) = \sum_{j=1}^n \sigma_r(j, m) v_r(n-j, m), \quad n \geq 1; \quad \dots \quad (4)$$

where $\sigma_r(j, m)$ denotes the sum of the r th powers of those divisors of j which do not exceed m , then it can be shown that $v_r(n, m)$ is the coefficient of x^n in the expansion of

$$J(x, m) = \prod_{j=1}^m (1-x^j)^{-j^{r-1}}; \quad |x| < 1.$$

Evidently $v_r(n, m)$ denotes the number of partitions of n into parts not exceeding m , element k being of k^{r-1} different types.

Thus $v_r(n, m) = v_r(n, n) = v_r(n)$, $m > n$. $\dots \dots \dots$ (5)

3. *Lemma.* If $(1-x)^{-1} \sum_{t=0}^{\infty} a_t x^t = \sum_{t=0}^{\infty} A_t x^t$,

and $a_t = \binom{t+s}{r}$ for every $t \geq 0$, $0 \leq s < r$; then

$$\binom{t+s+1}{r+1} \leq j A_t \leq \binom{t+s+j}{r+1}$$

The proof is simple and is left to the reader.

This immediately leads us to the inequality (Gupta 1942)

$$\binom{n-1+S_{r-1}(m)}{S_{r-1}(m)-1} \leq \prod_{j=1}^m j^{j^{r-1}} \cdot v_r(n, m) \leq \binom{n-1+S_r(m)}{S_{r-1}(m)-1}, \quad \dots \quad (6)$$

where $S_k(m)$ denotes the sum of the k th powers of positive integers $\leq m$.

Hence, if $m = o\left(\frac{1}{n^{\frac{1}{2r+1}}}\right)$,

$$\prod_{j=1}^m j^{j^{r-1}} \cdot v_r(n, m) \sim \binom{n-1}{S_{r-1}(m)-1}. \quad \dots \quad (7)$$

Again, following Hardy (1940), it can be shown that for large n ,

$$v_2(n) = \exp[\{C+o(1)\}n^{\frac{1}{2}}];$$

where $C = \frac{27}{4} \{1^{-3} + 2^{-3} + 3^{-3} + 4^{-3} + \dots\}$,

so that C is nearly 2.01.

The tables that follow give the values of $v_2(n, m)$ for values of $m \leq n \leq 50$.

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TABLE OF VALUES OF $r_2(n, m)$.

	24	25	26	27	28	$n \rightarrow$ $m \downarrow$
	1	1	1	1	1	1
	91	91	105	105	120	2
	2147	2507	2937	3422	3947	3
	16368	21454	27172	33938	42437	4
	60713	81800	1 09468	1 45526	1 92288	5
	1 32026	1 85413	2 59242	3 59395	4 95839	6
	2 11756	3 06667	4 41249	6 30771	8 96344	7
	2 83108	4 18175	6 14420	8 96439	13 01168	8
	3 38584	5 07293	7 55612	11 18679	16 47023	9
	3 78379	5 72173	8 60712	12 86679	19 13943	10
	4 05274	6 16987	9 34126	14 06249	21 06168	11
	4 22056	6 46585	9 83608	14 87585	22 39062	12
	4 34123	6 65812	10 15835	15 41496	23 27878	13
	4 41123	6 77838	10 36541	15 76286	23 86125	14
	4 45353	6 85338	10 49426	15 98471	24 23400	15
	4 47913	6 89850	10 57426	16 12215	24 47064	16
	4 49375	6 92570	10 62220	16 20715	24 61667	17
	4 50239	6 94118	10 65100	16 25791	24 70667	18
	4 50695	6 95030	10 66734	16 28831	24 76025	19
	4 50955	6 95510	10 67694	16 30551	24 79225	20
	4 51081	6 95783	10 68198	16 31559	24 81031	21
	4 51147	6 95915	10 68484	16 32087	24 82087	22
	4 51170	6 95984	10 68622	16 32386	24 82639	23
	4 51194	6 96008	10 68694	16 32530	24 82951	24
		6 96033	10 68719	16 32605	24 83101	25
23	2 90783		10 68745	16 32631	24 83179	26
22	2 90760	1 86475		16 32658	24 83206	27
21	2 90738	1 86453	1 18794		24 83234	28
20	2 90675	1 86432	1 18773	75278		
19	2 90555	1 86372	1 18753	75258	47330	
18	2 90308	1 86258	1 18696	75239	47311	
17	2 89876	1 86024	1 18588	75185	47293	
16	2 89060	1 85616	1 18367	75083	47242	
15	2 87684	1 84848	1 17983	74875	47146	
14	2 85284	1 83558	1 17263	74515	46951	
13	2 81336	1 81318	1 16059	73843	46615	
12	2 74836	1 77652	1 13979	72725	45991	
11	2 64528	1 71652	1 10595	70805	44959	
10	2 48446	1 62258	1 05095	67703	43199	
9	2 24446	1 47833	96660	62748	40379	
8	1 90138	1 26998	84042	55314	36005	
7	1 45154	98806	66714	44702	29685	
6	93074	65311	45329	31304	21313	
5	44726	32708	23711	17057	12146	
4	13226	10333	7911	6097	4586	
3	1812	1522	1282	1062	872	
2	78	78	66	66	55	
1	1	1	1	1	1	
$m \uparrow$ $n \rightarrow$	23	22	21	20	19	

	29	30	31	32	33	$\begin{matrix} \leftarrow n \\ m \\ \downarrow \end{matrix}$
	1	1	1	1	1	1
	120	136	136	153	153	2
	4557	5243	5978	6825	7763	3
	52423	64833	79354	97130	117824	4
	2 52521	3 29792	4 28316	5 53478	7 11596	5
	6 79175	9 26064	12 54360	16 91753	22 68267	6
	12 66146	17 78692	24 85086	34 54206	47 77165	7
	18 76826	26 93988	38 45134	54 62744	77 20947	8
	24 11642	35 13096	50 91511	73 44086	105 43419	9
	28 30942	41 67746	61 04421	89 01506	129 19384	10
	31 38150	46 53495	68 67766	100 90551	147 60476	11
	33 52602	49 97535	74 13982	109 52691	161 09612	12
	34 98046	52 32757	77 92308	115 54942	170 62863	13
	35 94051	53 90208	80 47346	119 65751	177 17993	14
	36 56556	54 93288	82 16456	122 39951	181 60133	15
	36 96316	55 59960	83 26520	124 20583	184 53085	16
	37 21459	56 02205	83 97359	125 37526	186 45134	17
	37 36921	56 28827	84 42089	126 12532	187 68956	18
	37 46421	56 45148	84 70190	126 59747	188 48129	19
	37 52061	56 55148	84 87370	126 89327	188 97820	20
	37 55421	56 61070	84 97870	127 07366	189 28888	21
	37 57313	56 64590	85 04074	127 18366	189 47786	22
	37 58417	56 66568	85 07754	127 24852	189 59286	23
	37 58993	56 67720	85 09818	127 28692	189 66054	24
	37 59318	56 68320	85 11018	127 30842	189 70054	25
	37 59474	56 68658	85 11642	127 32090	189 72290	26
	37 59555	56 68820	85 11993	127 32738	189 73586	27
	37 59583	56 68904	85 12161	127 33102	189 74258	28
	37 59612	56 68933	85 12248	127 33276	189 74635	29
		56 68963	85 12278	127 33366	189 74815	30
18	29601		85 12309	127 33397	189 74908	31
17	29583	18334		127 33429	189 74940	32
16	29566	18317	11297		189 74973	33
15	29518	18301	11281	6879		
14	29428	18256	11266	6864	4167	
13	29246	18172	11224	6850	4153	
12	28934	18003	11146	6811	4140	
11	28358	17715	10990	6739	4104	
10	27412	17187	10726	6596	4038	
9	25812	16327	10246	6356	3908	
8	23310	14887	9472	5924	3692	
7	19546	12731	8220	5236	3308	
6	14478	9658	6428	4193	2727	
5	8578	5986	4133	2819	1902	
4	3473	2551	1903	1364	992	
3	722	582	466	376	294	
2	55	45	45	36	36	
1	1	1	1	1	1	
$\begin{matrix} \uparrow \\ m \\ n \rightarrow \end{matrix}$	18	17	16	15	14	

	34	35	36	37	38	$\leftarrow n$ m \downarrow
	1	1	1	1	1	1
	171	171	190	190	210	2
	8771	9912	11172	12516	14028	3
	1 42930	1 72018	2 06925	2 47179	2 95105	4
	9 10563	11 59790	14 70798	18 57286	23 35838	5
	30 28345	40 21954	53 20139	70 03154	91 83768	6
	65 75350	90 08159	122 86196	166 84252	225 62210	7
	108 64828	152 16527	212 22670	294 70004	407 61562	8
	150 68833	214 42703	303 85111	428 80601	602 77426	9
	186 72473	268 70493	385 15321	549 81296	782 02516	10
	215 01761	311 93702	450 77448	648 91182	930 70765	11
	236 00585	344 35040	500 55526	724 87270	1046 01481	12
	250 96872	367 70178	536 73894	780 63867	1131 41675	13
	261 35714	384 04034	562 29146	820 32181	1192 71897	14
	268 41539	395 24639	579 93851	847 95871	1235 70357	15
	273 14235	402 79791	591 93619	866 86863	1265 34453	16
	276 25777	407 82566	599 97192	879 64192	1285 48681	17
	278 29123	411 12578	605 29857	888 15637	1299 02524	18
	279 59824	413 27221	608 78203	893 78056	1308 01623	19
	280 43164	414 64801	611 04143	897 44736	1313 93643	20
	280 95349	415 52308	612 48602	899 81973	1317 78657	21
	281 27887	416 06978	613 40276	901 33311	1320 27191	22
	281 47644	416 40995	613 97431	902 29152	1321 85408	23
	281 59644	416 61611	614 32927	902 88792	1322 85416	24
	281 66694	416 74111	614 54402	903 25767	1323 47541	25
	281 70854	416 81443	614 67402	903 48101	1323 85995	26
	281 73176	416 85763	614 75016	903 61601	1324 09188	27
	281 74520	416 88171	614 79496	903 69497	1324 23188	28
	281 75216	416 89563	614 81990	903 74137	1324 31366	29
	281 75606	416 90283	614 83430	903 76717	1324 36166	30
	281 75792	416 90686	614 84174	903 78205	1324 38832	31
	281 75888	416 90878	614 84590	903 78973	1324 40368	32
	281 75921	416 90977	614 84788	903 79402	1324 41160	33
	281 75955	416 91011	614 84890	903 79606	1324 41602	34
		416 91046	614 84925	903 79711	1321 41812	35
13	2485		614 84961	903 79747	1324 41920	36
12	2472	1479		903 79784	1324 41957	37
11	2460	1467	859		1324 41995	38
10	2427	1456	848	500		
9	2367	1426	838	490	282	
8	2250	1372	811	181	273	
7	2058	1268	763	457	265	
6	1722	1100	672	415	244	
5	1263	827	528	337	208	
4	688	492	328	227	143	
3	226	178	132	97	73	
2	28	28	21	21	15	
1	1	1	1	1	1	
\uparrow m $n \rightarrow$	13	12	11	10	9	

	39	40	41	42	$\leftarrow n$ m \downarrow
	1 210 15680 3 50154 29 26061	1 231 17444 4 15124 36 51688	1 231 19404 4 89414 45 40502	1 253 21540 5 76540 56 25896	1 2 3 4 5
	119 89881 303 86994 561 49926 844 07058 1108 06363	155 96450 407 65475 770 59691 1177 58492 1564 49107	202 05219 544 80026 1053 53320 1636 95286 2201 11771	260 85672 725 40570 1435 27040 2267 56643 3086 44183	6 7 8 9 10
	1330 07806 1504 10620 1634 22931 1728 34494 1794 85179	1894 23257 2155 59225 2352 75025 2496 52010 2598 79580	2688 53871 3079 02177 3376 31149 3594 73018 3751 24213	3803 41864 4384 13200 4830 14042 5160 40959 5398 62729	11 12 13 14 15
	1840 99819 1872 58963 1893 94573 1908 24304 1917 70904	2670 26988 2719 48352 2752 99007 2775 54801 2790 60171	3861 27973 3937 55652 3989 77524 4025 17566 4048 92836	5567 21545 5684 73475 5765 70433 5820 88755 5858 16825	16 17 18 19 20
	1923 92525 1927 95873 1930 55704 1932 20800 1933 24975	2800 54101 2807 05323 2811 27005 2813 98133 2815 70108	4064 73674 4075 14934 4081 95757 4086 35773 4089 18198	5883 11289 5899 67405 5910 55995 5917 66419 5922 24769	21 22 23 24 25
	1933 89585 1934 29518 1934 53570 1934 68070 1934 76530	2816 78450 2817 45545 2817 86957 2818 11868 2818 26868	4090 97052 4092 09561 4092 79141 4093 22032 4093 47802	5925 18491 5927 04224 5928 20900 5928 92965 5929 37335	26 27 28 29 30
	1934 81490 1934 84242 1934 85826 1934 86642 1934 87097	2818 35610 2818 40730 2818 43568 2818 45200 2818 46040	4093 63302 4093 72326 4093 77606 4093 80530 4093 82210	5929 63964 5929 79964 5929 89270 5929 94710 5929 97720	31 32 33 34 35
	1934 87313 1934 87424 1934 87462 1934 87501	2818 46508 2818 46730 2818 46844 2818 46883 2818 46923	4093 83074 4093 83555 4093 83783 4093 83900 4093 83940	5929 99448 5930 00336 5930 00830 5930 01064 5930 01184	36 37 38 39 40
8	160		1093 83981	5930 01225	41
7	152	86		5930 01267	42
6	145	79	48		
5	127	73	42	24	
4	97	58	37	19	
3	51	34	25	15	
2	15	10	10	6	
1	1	1	1	1	
\uparrow m	8	7	6	5	
$n \rightarrow$					

	43	44	45	46	$\leftarrow n$ m \downarrow
	1	1	1	1	1
	253	276	276	300	2
	23808	26316	29028	31908	3
	6 75794	7 91345	9 22483	10 74325	4
	69 46852	85 49811	104 89000	128 28386	5
	335 49194	430 07621	549 37160	699 57179	6
	962 41635	1272 43087	1676 61254	2201 92978	7
	1948 33405	2635 94015	3554 20354	4777 09946	8
	3130 40182	4307 27618	5907 46711	8076 72749	9
	4313 43932	6069 07123	8344 90336	11553 70959	10
	5363 39768	7539 72904	10567 02392	14766 16521	11
	6222 91066	8806 40546	12425 57162	17482 08509	12
	6889 03209	9796 66226	13891 49166	19642 90570	13
	7385 95663	10541 05024	15001 52898	21291 37868	14
	7746 85738	11085 15829	15818 30378	22512 00658	15
	8003 78098	11474 91373	16406 73234	23396 59978	16
	8183 97486	11749 75528	16824 04749	24027 23637	17
	8308 78452	11941 22848	17116 25841	24471 19143	18
	8394 37553	12073 20210	17318 79081	24780 39572	19
	8452 49913	12163 36840	17457 84721	24993 84332	20
	8491 65216	12224 41708	17552 56162	25139 93045	21
	8517 78684	12265 43927	17616 52651	25239 17586	22
	8535 10078	12292 76189	17659 41576	25306 05342	23
	8546 45998	12310 82861	17687 92632	25350 80742	24
	8553 86023	12322 66111	17706 74582	25380 50592	25
	8558 62707	12330 35737	17719 05162	25400 07820	26
	8561 67726	12335 30755	17727 04389	25412 85730	27
	8563 60338	12338 47071	17732 17741	25421 14558	28
	8564 81181	12340 46562	17735 45354	25426 46244	29
	8565 55731	12341 71572	17737 51724	25429 85154	30
	8566 01580	12342 48607	17738 80901	25431 98403	31
	8566 29068	12342 95935	17739 60421	25433 31747	32
	8566 45568	12343 24282	17740 09228	25434 13752	33
	8566 55156	12343 41282	17740 38434	25434 64038	34
	8566 60756	12343 51152	17740 55934	25434 94103	35
	8566 63852	12343 56912	17740 66086	25435 12103	36
	8566 65628	12343 60094	17740 72006	25435 22537	37
	8566 66540	12343 61918	17740 75274	25435 28617	38
	8566 67047	12343 62854	17740 77146	25435 31971	39
	8566 67287	12343 63374	17740 78106	25435 33891	40
	8566 67410	12343 63620	17740 78639	25435 34875	41
	8566 67452	12343 63746	17740 78891	25435 35421	42
	8566 67495	12343 63789	17740 79020	25435 35679	43
		12343 63833	17740 79064	25435 35811	44
4	13		17740 79109	25435 35856	45
3	9	6		25435 35902	46
2	6	3	3		
1	1	1	1	1	
\uparrow m $n \rightarrow$	4	3	2	1	

47	48	49	50	$\leftarrow n$ $m \downarrow$
1	1	1	1	1
300	325	325	351	2
35064	38469	42069	45999	3
12 46034	14 43675	16 66409	19 21549	4
156 42512	190 18801	230 58592	278 80409	5
887 89182	1123 57406	1417 38607	1783 91142	6
2882 58242	3761 90535	4894 57175	6349 48264	7
6400 31762	8549 11171	11384 88189	15117 52576	8
11008 75106	14960 43757	20271 41589	27389 87134	9
15948 61891	21951 97322	30129 37489	41239 49246	10
20574 54714	28587 31039	39611 77639	54741 93007	11
24527 24998	34318 97140	47888 93614	66653 11966	12
27699 77492	38957 57302	54648 53028	76465 26317	13
30137 65589	42548 93905	59918 69875	84170 88823	14
31954 44614	45241 99240	63895 48545	90021 97453	15
33278 43454	47215 73488	66826 90425	94355 88973	16
34227 42979	48637 61879	68948 92823	97510 19859	17
34898 76130	49648 54478	70463 80220	99774 97884	18
35368 72383	50359 50977	71534 91143	1 01380 88585	19
35694 67063	50855 95077	72284 78783	1 02510 96545	20
35918 94181	51197 57736	72805 62374	1 03299 26786	21
36072 92925	51432 61381	73164 62744	1 03845 21612	22
36175 79582	51592 68254	73410 39532	1 04220 63201	23
36245 58374	51700 96634	73577 43448	1 04477 11029	24
36292 20249	51773 66209	73690 23298	1 04651 11554	25
36323 98893	51822 14559	73765 83656	1 04768 42598	26
36343 41399	51854 21997	73816 18481	1 04846 93739	27
36356 66639	51875 29781	73849 44713	1 04899 15039	28
36365 25068	51889 92351	73871 27775	1 04933 60065	29
36370 75088	51897 90381	73885 47675	1 04956 18405	30
36374 25295	51903 58735	73894 65306	1 04970 85635	31
36376 45423	51907 20239	73900 51994	1 04980 32867	32
36377 82934	51909 47246	73904 24795	1 04986 37889	33
36378 67424	51910 88924	73906 58681	1 04990 21987	34
36379 19189	51911 75899	73908 94526	1 04992 62752	35
36379 50113	51912 29143	73908 93986	1 04994 12764	36
36379 68613	51912 60926	73909 48709	1 04995 94709	37
36379 79329	51912 79926	73909 81351	1 04995 60911	38
36379 85569	51912 90924	73910 90851	1 04995 94412	39
36379 89009	51912 97324	73910 12131	1 04996 14412	40
36379 90977	51913 90850	73910 18691	1 04996 25974	41
36379 91985	51913 92866	73910 22303	1 04996 32694	42
36379 92544	51913 93898	73910 24367	1 04996 36392	43
36379 92808	51913 94470	73910 25423	1 04996 38504	44
36379 92943	51913 94740	73910 26008	1 04996 39584	45
36379 92989	51913 94878	73910 26284	1 04996 40182	46
36379 93036	51913 94925	73910 26425	1 04996 40464	47
* *	51913 94973	73910 26473	1 04996 40608	48
* *	* *	73910 26522	1 04996 40657	49
* *	* *	* *	1 04996 40707	50

A NOTE ON KINETICS OF FUSION.

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(Communicated by Dr. F. C. Auluck, F.N.I.)

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Recently Penner (1948) has applied the well-known theory of rate processes to the kinetics of fusion and evaporation. Various models have been suggested from time to time for the liquid state to render it amenable to statistical treatment. One of these models due to Fürth (1941) has been very extensively used due to its great simplicity. The object of the present note is to apply Fürth's theory to the kinetics of fusion. By combining the result obtained here with Penner's expression a relation between Lindemann frequency and surface tension is obtained.

The rate j at which any chemical or physical process takes place is governed by the equation

$$j = \frac{(kT)F^*}{(h)F} e^{-\epsilon_{\text{act}}/kT}, \quad \dots \dots \dots (1)$$

where F^* and F denote the partition function of the activated complex and the unactivated state respectively while ϵ_{act} represents the energy which must be supplied to the system before the reaction will occur. Taking Einstein's model of oscillators for the solid and substituting for F^* and F Penner obtains from (1) the rate of fusion

$$j = \nu e^{-\epsilon_f/kT}, \quad \dots \dots \dots (2)$$

where ϵ_f is the latent heat of fusion and ν the Lindemann frequency.

According to Fürth's theory the difference between the solid and the liquid state consists merely in the presence of a large number of holes in the latter. It is therefore in accord with the existing theory if we assume that the rate of fusion is simply the rate at which the holes are created. Fürth takes the time for the creation or the destruction of a hole to be equal as the two processes are exactly reversible. Further he shows that the time t in which a hole of radius r is annihilated is given by

$$t = \frac{r}{3} \left(\frac{2\pi m}{kT} \right)^{\frac{1}{2}} e^{A/kT}, \quad \dots \dots \dots (3)$$

where m is the mass of the molecule and A the so-called work function. Replacing r by the average volume \bar{v} of the hole the rate of fusion

$$j = 3 \left(\frac{4\pi}{3\bar{v}} \right)^{\frac{1}{2}} \left(\frac{kT}{2\pi m} \right)^{\frac{1}{2}} e^{-A/kT}. \quad \dots \dots \dots (4)$$

When the liquid is under its own saturation vapour pressure the average volume of a hole

$$\bar{v} = .68 \left(\frac{kT}{\sigma} \right)^{\frac{2}{3}}, \quad \dots \dots \dots (5)$$

where σ is the surface tension. Substituting for \bar{v} in (4) we have after some simplification

$$j = 2.2 \left(\frac{\sigma}{m} \right)^{\frac{1}{2}} e^{-A/kT} \quad \dots \quad \dots \quad \dots \quad (6)$$

If after Fürth we identify A with the latent heat of fusion ϵ_f then comparing (2) and (6) we have

$$\nu = 2.2 \left(\frac{\sigma}{m} \right)^{\frac{1}{2}} \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

It is interesting to note that Sibaiya and Rama Rao (1939) in an attempt to explain surface tension from the molecular stand point have obtained a similar relation. They have shown

$$\nu = C \left(\frac{\sigma}{m} \right)^{\frac{1}{2}} \quad \dots \quad \dots \quad \dots \quad \dots \quad (8)$$

where $C = (\gamma/\sqrt{2\pi\alpha})$, α being the amplitude of vibration and γ the mean distance between the molecular centres. A comparison between (7) and (8) suggests that C must be a constant. This conclusion is also supported by the calculations of Sibaiya and Rama Rao who have evaluated C for forty-five substances (including elements and compounds) by taking the experimental value of σ and ν from Lindemann's relation.

$$\nu = 2.8 \times 10^{10} \sqrt{\left(\frac{T_s}{Mv} \right)} \quad \dots \quad \dots \quad \dots \quad (9)$$

Here T_s is the melting point, M the molecular weight and v the molecular volume. The mean value of C obtained by them is 2.34 which is not far from the value given by equation (7).

My thanks are due to Prof. D. S. Kothari and Dr. F. C. Auluck for their help and guidance during the course of the work.

SUMMARY.

Kinetics of fusion is treated here on the basis of Fürth's hole model. Penner has recently obtained expressions for the rate of fusion and evaporation on the well-known theory of rate processes. Comparing the result obtained here with Penner's expression a relation between Lindemann frequency and surface tension is obtained. A similar result has been given by Sibaiya and Rama Rao in an attempt to explain the phenomenon of surface tension from molecular standpoint.

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THERMAL IONIZATION OF THALLIUM.

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1. INTRODUCTION.

The theory of Thermal Ionization was first given by M. N. Saha (1920, 1921) and was further developed by Darwin and Fowler (1923). In order to test the theory some experiments were carried out by Saha, Sur and Majumdar (1927) who showed qualitatively from the increase in electrical conductivity that the alkali metals could be ionized by heating their vapours to temperatures of about 2000°C. The quantitative verification of the theory was first obtained by I. Langmuir and K. H. Kingdon (1925) for caesium by an ingenious method in which caesium atoms striking the high temperature filament of an ordinary thermionic valve become ionized. This method was utilized by Killian (1926) for rubidium and potassium, by E. Meyer (1930) for potassium and by Morgulis (1934) for sodium. The method, however, involves uncertainties due to the adsorption of the atoms and the ions on the surface of the filament.

A simple and direct method was developed by Srivastava (1940*a*, 1940*b*) for studying the thermal ionization of substances. In this method the vacuum graphite furnace constructed by Saha and Tandon (1936), was utilized but the internal arrangement was somewhat modified. Essentially the apparatus consists of a graphite tube (Fig. 1) heated to about 1600°C. by a current of the order of a thousand amperes from a low-tension transformer. This tube has a fine circular hole on one side while on the other side an auxiliary furnace containing the substance under

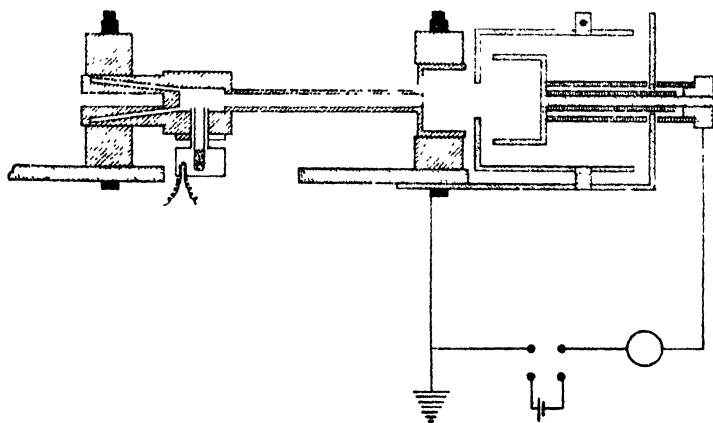


FIG. 1.

* This work was done while this author was at Allahabad University.

investigation is fitted gas-tight into it. This auxiliary furnace is thus heated by conduction and the vapour of the substance formed there enters the main furnace where it gets ionized. The products of ionization effuse out through the narrow orifice and the effusion beam, further limited by another hole of radius r and placed at a distance d from the effusion hole, is collected by a Faraday cylinder to which suitable positive or negative potentials are applied. The respective currents are measured by a sensitive galvanometer connected to the Faraday cylinder.

This method was utilized by Srivastava (1940*a*, 1940*b*) for studying the thermal ionization of barium and strontium at different temperatures. Later it was applied by Bhatnagar (1943) to sodium and potassium, by Srivastava and Bhatnagar (1946) to lithium and by Bhatnagar (1947*a*, 1947*b*) to calcium and aluminium. In the present paper the same method has been applied to investigate the thermal ionization of Thallium.

2. THEORY.

The ionic and electronic currents are proportional to the respective pressures of ions and electrons in the main graphite furnace, and depend upon the geometry of the arrangement. Srivastava (1938) has shown that the ionic current is given by

$$i_r^+ = \frac{ep_i S}{\sqrt{(2\pi m_i kT)}} \cdot \frac{r^2}{r^2 + d^2}, \quad \dots \quad (1)$$

and the electronic current

$$i_r^- = \frac{ep_e S}{\sqrt{(2\pi m_e kT)}} \cdot \frac{r^2}{r^2 + d^2}, \quad \dots \quad (2)$$

where p_i and p_e denote the partial pressures and m_i , m_e the masses of ions and electrons respectively, S the area of the effusion hole, r the radius of the limiting diaphragm, d the distance between the effusion hole and the limiting diaphragm, and T the temperature of the ions inside the furnace. The equilibrium constant is given by

$$K = \frac{p_i \cdot p_e}{p_a} = \frac{2\pi kT}{e^2 S^2} \left(\frac{r^2 + d^2}{r^2} \right)^2 \frac{i_r^+ i_r^-}{p_a} \sqrt{(m_i \cdot m_e)}. \quad \dots \quad (3)$$

Expressing the pressures in atmospheres

$$K = \frac{2\pi kT}{e^2 S^2} \left(\frac{r^2 + d^2}{r^2} \right)^2 \frac{i_r^+ i_r^-}{p_a} \frac{\sqrt{(m_i m_e)}}{(1.013 \times 10^6)^2}. \quad \dots \quad (4)$$

All the quantities occurring in this equation are either experimentally measured or otherwise known and hence the value of K can be experimentally determined.

The modified ionization formula due to Darwin and Fowler (1923) is

$$\ln \frac{p_i p_e}{p_a} = -\frac{\chi_1}{kT} + \frac{5}{2} \ln T + \ln \frac{g_e (2\pi m_e)^{\frac{3}{2}} k^{\frac{5}{2}}}{h^3} - \ln b(T) + \ln b'(T), \quad \dots \quad (5)$$

where χ_1 denotes the energy required to ionize the unexcited atom, g_e the weight factor of the electron, and $b(T)$ and $b'(T)$ are given by

$$b(T) = g_1 + g_2 e^{-(\chi_1 - \chi_2)/kT} + \dots + g_n e^{-(\chi_1 - \chi_n)/kT} + \dots$$

$$b'(T) = g_{i,1} + g_{i,2} e^{-(\chi_{i,1} - \chi_{i,2})/kT} + \dots + g_{i,n} e^{-(\chi_{i,1} - \chi_{i,n})/kT} + \dots$$

Substituting the various values in the above equation and expressing pressures in atmospheres we have

$$\log \frac{p_i p_s}{p_a} = -\frac{U}{4.573T} + \frac{5}{2} \log T - 6.479 + \log 2 + \log b'(T) - \log b(T), \quad \dots (6)$$

where U is the energy of ionization of thallium vapour in calories given by $NeV_i/300J$, and V_i denotes ionization potential in volts, being in this case equal to 6.106 volts. The value of U comes out to be 140.6 k.cal.

The quantity p_i , the pressure of the thallium vapour in the main furnace, cannot be directly determined. Due to thermal transpiration this will be different from the vapour pressure in the auxiliary furnace. For our purpose we assume the full Knudsen effect, i.e.

$$\frac{p}{p'} = \sqrt{\frac{T'}{T}}$$

where T and T' denote the temperatures of the main and auxiliary furnaces. The error due to this assumption in the value of K is negligible compared to the possible errors in measuring T .

The only available data on the vapour pressure of Tl are those due to J. Fischer (1935) and F. F. Coleman and A. Egerton (1935). These observed pressures are plotted on a graph (Fig. 2) in which $\log p$ represents the ordinate and $1/T$ the abscissa. The values do not lie well on one straight line and in particular the slopes of the two lines obtained from the plot of these two investigations is different. We have therefore drawn such a straight line which passes through most of the points and has a slope equal to $\lambda_0/4.573$ where λ_0 is the latent heat of vaporization of thallium in cal. and is equal to 42.53 k.cal. as determined by K. K. Kelley (1935). This straight line has been used in determining the vapour pressure of thallium.

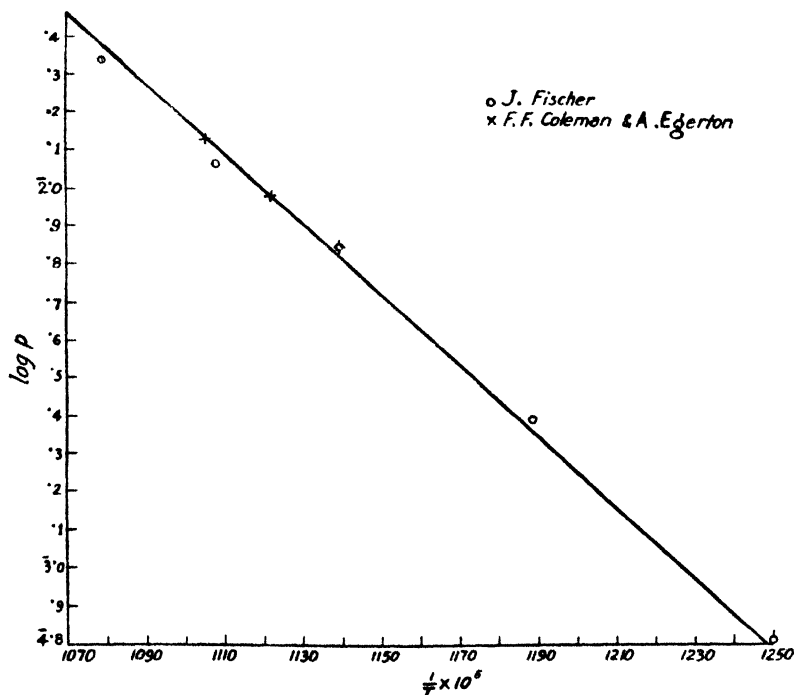


FIG. 2.

TABLE I.

Mean temp. of main graphite furnace in °K.	Temp. of auxiliary furnace in °K.	Vapour pressure in auxiliary furnace in mm.	Vapour pressure in main furnace in mm.	Negative deflection in mm. d^-	Positive deflection in mm. d^+	log K in atmos./cm. ²	$b(T)$	U (expt.) in k.cal.	log K (theor.) in atmos./cm. ²
1850	903	1.309×10^{-2}	1.851×10^{-2}	43×30	9.5	$\overline{16.967}$	2.0093	141.5	$\overline{15.0671}$
1826	881	7.161×10^{-3}	1.030×10^{-2}	67×10	6.1	$\overline{16.739}$	2.0086	141.4	$\overline{16.8329}$
1804	890	9.016×10^{-3}	1.283×10^{-2}	88×10	4.5	$\overline{16.625}$	2.0079	140.5	$\overline{16.6198}$
1793	879	6.761×10^{-3}	9.656×10^{-3}	18×30	4.0	$\overline{16.485}$	2.0076	140.7	$\overline{16.5034}$
1784	887	8.511×10^{-3}	1.207×10^{-2}	59×10	4.0	$\overline{16.422}$	2.0074	140.5	$\overline{16.4079}$
1769	879	6.761×10^{-3}	9.590×10^{-3}	47×10	2.5	$\overline{16.215}$	2.0070	140.9	$\overline{16.2587}$
1726	860	3.926×10^{-3}	5.562×10^{-3}	63×3	2.0	$\overline{17.948}$	2.0060	139.4	$\overline{17.8022}$
Mean = 140.7									

Diameter of the effusion hole = 0.225 cm.
 Diameter of the limiting diaphragm = 0.85 cm.
 Distance between the effusion hole and the limiting diaphragm = 1.2 cm.
 Current sensitivity of the galvanometer = 7.891×10^{-10} amp./mm.

3. EXPERIMENTAL PROCEDURE AND RESULTS.

A detailed description of the apparatus and the procedure to be followed has been given by Srivastava (1940a). The graphite tube, before being used, was degassed by intermittent prolonged heating for nearly 50 hours till the current from the empty tube becomes negligible. The temperature of the main graphite furnace was measured by means of a Leeds Northrup optical pyrometer which had three ranges. The temperature of the auxiliary furnace was measured by means of a calibrated standard Chromel-alumel thermocouple which was chosen on account of its great sensitivity in this region. The experiments were done with spectroscopically pure thallium and the effusion currents measured with a sensitive moving coil galvanometer which was critically damped. The results obtained are given in Table I.

4. DISCUSSION OF RESULTS.

For a quantitative test of the ionization formula, the values of the ionization constant K at different temperatures and pressures of thallium vapour are calculated theoretically from equation (6) and the values of $\log K$ (theor.) thus obtained given in column (10) of the table. These may be compared with the corresponding values of $\log K$ (exp.) obtained directly from a measurement of the ion currents. It will be seen that the agreement is very close and well within the limits of experimental error which in this case is mainly due to errors in the measurement of the temperature of the graphite furnace. The values of U as obtained from equation (6) by using the values of $\log K$ (exp.), are given in the column (9) of the table, giving a mean value of 140.7 k.cal. which agrees closely with the spectroscopic value of 140.6 k.cal. Thus these experiments fully verify the ionization theory for the case of thallium.

SUMMARY.

In this paper the thermal ionization of thallium vapour has been experimentally investigated by means of the vacuum graphite furnace already described elsewhere. Experiments have been carried out at various temperatures and pressures of thallium vapour and equilibrium concentrations of Tl^+ and electrons inside the furnace have been determined by the effusion method. From these the equilibrium constant and the energy of ionization have been calculated. The results obtained agree, within the limits of experimental error, with the theory of thermal ionization and the known spectroscopic value of the ionization potential of thallium.

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NOTES ON THE EMBRYONIC DEVELOPMENT OF THE TRANSPARENT GOBY, *Gobiopterus chuno* (HAMILTON).¹

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(Communicated by Dr. T. J. Job, F.N.I.)

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INTRODUCTION.

In July, 1948, Mr. A. David of this Research Station, drew my attention to certain specimens of tiny fish with well-developed eggs in his collections from the Kulti river. On detailed examination I found them to belong to a Sicydiaphine Goby, *Gobiopterus chuno*. Mature specimens of this species were subsequently collected by me in September, 1948, from Kulti and an account of the embryonic development of *Gobiopterus chuno* which was worked out is given in this paper.

The minute transparent goby, *Gobiopterus chuno* (Hamilton)² that is common in brackish water fields near the Kulti outfall, in the River Hooghly and also in the Pulta settling tanks and filter beds, was found to be mature during June, July and October, 1948. Since fertilized eggs could not be collected from these natural habitats, artificial fertilization was attempted in the laboratory successfully on the 29th September, 1948, at Barrackpore, by stripping eggs from the ripe female into a petri-dish with a little water and teasing the dissected-out testis of the ripe male, in the dish.

This minute goby is abundant in fresh-water tanks of the Jobra Fish Farm, Cuttack. It was found to breed in these tanks almost throughout the year. By keeping ripe specimens of either sex in the laboratory aquaria the process of deposition of eggs was fully observed during November, 1949. Artificial fecundation of ova also was successfully repeated and the different stages were re-examined for confirmation. The hatchlings lived up to 12 hours in the laboratory.

¹ Published with the permission of the Chief Research Officer, Central Inland Fisheries Research Station, Barrackpore.

² (*Gobius chuno*, Hamilton) *vide* Hora, S. L. (1934)—Systematic position of Hamilton's species of Gobiod fish from the Ganges. *Rec. Ind. Mus.*, 36; 483-490.

Our knowledge of the life history of Indian Gobiids is still very meagre, though the contributions of Bhattacharya (1916), Raj (1916), Aiyar (1935), Jones (1937) and Alikunhi *et al.* (1948) have helped in elucidating the embryonic and larval life of species like *Gobius ostereicola*, *Acentrogobius neilli*, *A. viridipunctatus* and *Glossogobius giuris*. *Gobiopterus chuno* is usually abundant in many carp nurseries under observation in Orissa, and the rôle of this 'weed fish' in the pond economy has to be correctly assessed for profitable carp culture. An intimate knowledge of the life habits of the species is essential for any such assessment and the following account of its early development will form a useful link in our knowledge of the species.

Pillay and Sarojini (1950) have recently published their observations on the larval development of *Gobiopterus chuno*.

BREEDING SEASON AND FECUNDITY.

As already pointed out, gravid females have been collected during January to November, indicating that the species breeds almost throughout the year. The adult males are easily distinguished from the females by the presence of a distinct fingerlike genital papilla; the corresponding structure in the female being a stouter prominence. The body being always of glassy transparency, the ovaries in the gravid females are clearly seen through by the naked eye. The ovarian eggs are transparent; some scattered chromatophores are present in the ovarian wall and in some specimens the entire ovary has a light pinkish tinge. 140 to 150 eggs mature at a time. The ova are closely packed in the ovary and the immature eggs and early oocytes too are generally present in considerable numbers in the ripe ovaries. The maximum length of the adult fish, so far collected by me is only 25 mm. For the size of the adult fish the eggs are relatively large. Deposition of eggs was observed by keeping ripe specimens in glass aquaria in the laboratory. The fish was swimming about mostly near the bottom; the genital papilla appeared highly tumid and extended. Eggs were slowly coming out in ones or twos and since the fish was moving near the bottom, as soon as the egg was coming out of the genital papilla, dirt and particles of debris began to stick to it, indicating that the egg is sticky in nature. The genital papilla was often touching the bottom of the aquarium, and the eggs as they came out, adhered to the bottom.

EMBRYONIC DEVELOPMENT.

(A) *Unfertilized Egg* :—(FIG. 1.)

The unfertilized mature egg is more or less spherical in shape and has an average diameter of 0.54 mm. The egg membrane is slightly swollen. There is a distinct micropylar opening around which numerous fine radiating adhesive filaments are present. The egg gets attached to some substratum by means of these filaments. The yolk which often has a yellowish tinge (when preserved) is coarsely granulated and has several oil globules of different size.

(B) *Fertilized Egg* :—(FIG. 2.)

Immediately after fertilization the zona radiata begins to swell up considerably and within five minutes it forms an oval capsule enclosing the egg. The capsule continues to swell up and within ten minutes becomes characteristically pear-shaped. The outer surface of the zona radiata appears finely striated longitudinally. The average dimensions of these egg capsules are as follows :—

Total length of the egg capsule	..	..	1.12 mm.
Maximum width of the egg capsule	..	..	0.73 mm.
Diameter of the fertilized egg	..	..	0.45 mm.

A streaming movement of the egg protoplasm now takes place. The egg appears in two distinct halves, the lower half, nearer to the attached portion of the egg capsule, of accumulated protoplasm in the form of a finely granular blastodisc and the upper half forming the bulk of the egg, representing the yolk (Fig. 3).

(C) *Early Segmentation* :—

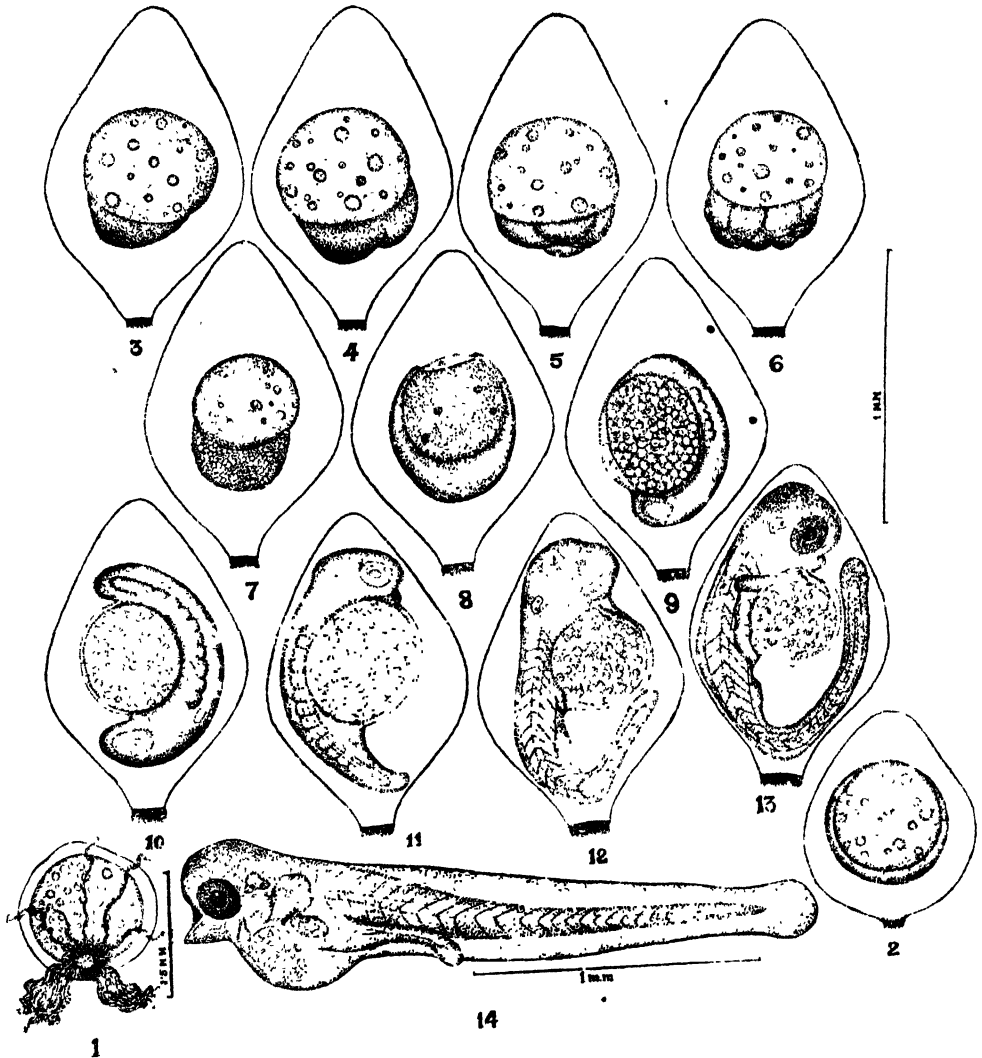
40 minutes after fertilization the cap like blastodisc undergoes the first cleavage to form the two blastomeres (Fig. 4). The second cleavage takes place at the end of the first hour (Fig. 5); while the 8-celled stage is reached at the close of the next half hour (Fig. 6). Two hours after fertilization, the 4th cleavage results in 16-cells. Subsequent divisions rapidly follow and in three hours and fifteen minutes after fertilization, the blastodisc is transformed into a cluster of small cells forming the blastoderm (Fig. 7).

(D) *Formation of the Embryo*

The crown of blastoderm cells now begin invasion of the yolk, spreading over the latter as a thin layer. About five hours after fertilization, the embryo is indicated as a median thickening of the blastoderm. 40 minutes later the head and tail ends of the embryo are distinguishable. Two myotomes are visible at the hind portion of the embryo which is slightly elongated. 17 hours after fertilization, the embryo gets further elongated and measures 0.60×0.17 mm. The rudiments of the optic cups appear, and five myotomes are differentiated. The head of the embryo is directed towards the base of the capsule (Fig. 9). Two and a half hours later, the embryo becomes roughly C-shaped and measures 0.66×0.22 mm. (Fig. 10). The auditory vesicles have appeared and 10 myotomes are visible. The head and tail ends of the embryo are beginning to get free from the yolk mass which is steadily being used up. A narrow space has appeared between the head and the yolk, locating the position of the heart. Within another two hours, further differentiation takes place and the embryo measures 0.72 mm. \times 0.30 mm. Tail is further elongated and the lens has appeared in the optic cup. 13 myotomes have been differentiated and the embryonic fin fold is clearly seen around the tail. Rudiment of the heart has appeared but has not begun pulsating. The embryo begins to execute faint side to side twitching movements of the tail. Between the 21st and 24th hours after fertilization, it affects a change in its orientation within the egg capsule, by a complete reversal of the position of the head, which accordingly becomes nearest to the distal end of the egg capsule (Fig. 11). In the $27\frac{1}{2}$ hours old embryo, the heart begins pulsating and two minute concretions appear in each of the auditory vesicles. The dorsal and ventral fin folds are better differentiated. The pulsations of the heart are regular and rapid, at the rate of about 108 beats per minute. 17 myotomes are seen.

Circulation of blood is fairly well established when the embryo is about 38 to 42 hours old, and the rate of heart beats increases to 155 per minute. The hind portion of the alimentary canal is indicated (Fig. 12). The tail end is elongated and curved forwards. The embryo moves frequently within the egg capsule. In the 45 hours old embryo, the eyes begin to get slightly pigmented. The rudiments of the pectoral fins appear as bud-like prominences. In another 9 hours, the eyes get fully pigmented and dark. The yolk is reduced to a small rounded mass. The auditory vesicles are now closer to the eyes. The alimentary canal is well differentiated. The total length of the embryo is now about 1.62 mm., the post-anal portion is longer than the pre-anal. Pectoral rudiments are larger and on the dorsal side, the embryonic fin fold is seen to commence from the nape.

In the 62 hours old embryo, the rudiment of the air bladder is visible as a small oval structure on the dorsal aspect of the yolk mass (Fig. 13). The buccal



TEXT-FIGS. 1 TO 14.

invagination is clearly indicated. The eyes are dark and shining. The pectoral rudiments are larger and flap-like. Blood is now red in colour. The embryo makes constant vigorous movements and when about 84 hours old, it is ready for hatching.

HATCHING AND HATCHLING.

The rupture of the egg capsule takes place near its distal end. The head portion of the embryo presses on the distal part of the capsule where the maximum strain is felt owing to the vigorous movements of the embryo. During hatching the head portion first comes out of the capsule.

The hatchling (Fig. 14) is very slender and measures 2.2 mm. in length. The eyes are fully pigmented and the mouth and anal openings have appeared. The anus is very anterior in position and is situated at the level of the 7-8th myotome.

A small yolk mass still remains. The dorsal embryonic fin fold commences at about the level of the hind portion of the yolk mass. Ventrally there is a small pre-anal fin fold. The tip of the notochord is straight and the caudal fin is rounded. A single chromatophore is present, ventrally midway between the anus and the tip of the tail. Two or three chromatophores are present on the dorsal aspect of the air bladder also.

DISCUSSION.

Like many other gobiids, *G. chuno* appears to be a perennial spawner. For the tiny fish, the ovarian eggs are larger than those of *Acentrogobius neilli* which grows to more than three times the length of *G. chuno*. The shape of the egg capsule is characteristic and is easily distinguished from that of *A. neilli*, *A. viridipunctatus* or *G. giuris*. The period of incubation is longer than in *A. neilli* and shorter than in *A. viridipunctatus*, but this is found to fluctuate with the temperature of the water. The differentiation of structure is typical of Gobiids. The change in the orientation of the embryo soon after it begins movement within the egg capsule is interesting. While Aiyar (1935) does not specially mention this change in position of the embryo in *A. neilli*, his figures 10 and 11 seem to indicate that such a change does take place in that species; even though at the stage shown in his figure 11, the embryo had not commenced movement. In *A. viridipunctatus* the reorientation appears to take place at an earlier stage (Jones, 1937); while in *Boleophthalmus boddarti* such a change is indicated more or less at the same stage as in *A. neilli* (vide figures 58 and 59, Jones, 1937). Alikunhi *et al.* (unpublished) has also observed that in *G. giuris* a similar reorientation of the embryo takes place within the egg capsule. The relative density of the yolk and protoplasm during the different phases of embryonic differentiation and hatching requirements are perhaps responsible for this reorientation in the position of the embryo.

The slender hatchling is a little longer than that of *A. neilli* and is in more or less the same stage of development as the latter. The scarcity of pigment in the hatchling is in conformity with the condition in the adult which is of an almost glassy transparency.

SUMMARY.

Gobiopterus chuno is common in brackishwater fields and is often found in rivers and freshwater ponds. It is found to breed almost the whole year round. The early development of this species was worked out by artificial fertilization of eggs. The eggs, with an average diameter of 0.54 mm., are sticky and get attached to objects by means of adhesive filaments. After fertilization the zona radiata swells up into a pear-shaped egg capsule and measures about 1.12 mm. in length. The yolk is pale yellowish in colour and coarsely granulated. The period of incubation lasts 80 to 96 hours. The hatchling, 2.2 mm. long, has a single chromatophore mid-ventrally behind the anal region and a small patch over the air bladder. The eyes are fully pigmented, the mouth is fairly well formed, the air bladder is present and pectorals are functional.

ACKNOWLEDGEMENTS.

I have pleasure to record here, my indebtedness to Mr. K. H. Alikunhi, for his guidance, helpful criticisms and kind encouragement in the completion of this work. My thanks are due to Mr. S. Jones for the valuable suggestions he offered. I owe a debt of gratitude to Dr. T. J. Job, for kindly going through the manuscript critically and giving me the benefit of his invaluable experience.

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EXPLANATION OF TEXT-FIGURES.

FIGS. 1 TO 14.

Developmental stages of *Gobiopterus chuno* (Hamilton).

- FIG. 1. Unfertilized, Ovarian egg; 0.54 mm.
- FIG. 2. Egg, 5 minutes after fertilization.
- FIG. 3. Fertilized egg, with capsule fully swollen.
- FIG. 4. Two-celled stage; 40 minutes after fertilization.
- FIG. 5. 4-celled stage; 1 hour after fertilization.
- FIG. 6. 8-celled stage; 1½ hours after fertilization.
- FIG. 7. 3 hours after fertilization.
- FIG. 8. 8 hours after fertilization.
- FIG. 9. Early embryo; 17 hours after fertilization.
- FIG. 10. Early embryo; 19½ hours after fertilization.
- FIG. 11. Embryo; 21½ hours after fertilization.
- FIG. 12. Embryo; 38½ hours after fertilization.
- FIG. 13. Embryo; 62 hours after fertilization.
- FIG. 14. Newly hatched larva; 84 hours after fertilization.

EMBRYO CULTURE AS AN AID TO SEED TESTING.¹

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(Communicated by Dr. B. P. Pal, F.N.I.)

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INTRODUCTION.

In seed-testing practice, one often encounters a varying proportion of shrivelled seeds within a sample of good, sound seeds. The majority of such shrivelled seeds may not germinate when the usual germination test is employed, and thus such seeds are classed under 'seeds incapable of germination,' 'bad seeds,' etc., by the seed analysts. The healthy and sound seeds are only tested for germination.

In connection with seed-testing of samples of foodgrains obtained from the local vendors, Mukherji (1950) found that the percentage of 'shrivelled, small and bad seeds' in samples of red maize was 13.80 and 7.11 (out of 20.47 and 14.40 per cent of total impurities) when calculated on number and weight-basis respectively. Presence of such a high proportion of shrivelled seeds reduces the market price of the samples to a considerable extent.

An investigation was carried out in order to get an idea about:— (i) the percentage of the shrivelled seeds that are potentially capable of germination, but owing to the under-nourished state of the embryos and their unfavourable environmental conditions, do not germinate under the usual conditions, and (ii) the effect of such shrivelled seeds on growth and development of the plants.

EXPERIMENTATION.

While the average weight² of the shrivelled seeds was 74.24 gm., which is about half the weight of the sound and healthy seeds, it was found that there were considerable proportions of seeds varying in weight from 20 to 120 gm. Thus, two sets of seeds were distinguished that varied in weight and hence in the degree of shrivelling, viz., set (1) seed-weight 20 to 60 gm., and set (2) seed-weight 80 to 120 gm., apart from a 'control set,' viz., set (3) normal seed-weight of 155 gm., and germination test, as usually adopted in seed-testing practice, and described by Pal and Mukherji (1950), was done. The result is tabulated in Table I, column 2.

It was observed that seedlings developed from the seeds of set (1) were very weak and delicate, those from set (2) were stronger but less so than those from set (3). Thus, there was a direct correlation between the degree of shrivelling and the reduction of vigour of the plants. In order to look into the question of whether under-nourishment and unfavourable surroundings for the embryo were the causes for the low germination percentage and loss of vigour of the seedlings developed from the shrivelled seeds, artificial culturing of embryos from seeds of the above three sets was resorted to. Seeds were sterilised by treatment with 2% Mercuric chloride in 50% alcohol for 90 seconds and then washed with sterilised distilled

¹ This work was done during the tenure of a research fellowship awarded by the National Institute of Sciences of India.

² All the seed-weights are given in terms of 1,000 seeds (Absolute weight) for the sake of convenience.

water 4 to 6 times. Seeds were soaked for 16 hours in sterilised water and embryos were excised out of them inside a culture room provided with a germicidal ultraviolet lamp. The embryos were cultured in White's (1934) nutrient medium modified by Purvis (1944) and further modified by the author. The medium was prepared as follows:—

Substance.	Concentration.	Substance.	Concentration.
KCl ..	0.87 m.mol. per litre	KNO ₃ ..	0.80 m.mol. per litre
MgSO ₄ ..	0.30 " " "	Ca(NO ₃) ₂ ..	0.60 " " "
KH ₂ PO ₄ ..	0.09 " " "	Sucrose ..	2.5%
FeSO ₄ ..	0.003 " " "	Agar ..	2.5%

The cultures were kept at 20° to 21°C. in an electrically-controlled constant-temperature chamber with continuous ventilating arrangement, for 10 days, after which germination count was made. The results are tabulated in Table I, column 3. That there was a definite increase in the percentage of germination in both the sets, i.e., set nos. (1) and (2), is apparent from the calculated data tabulated in Table I, column 4. The seedlings developed in cultures from the embryos of seeds of set (1) were weaker in vigour of growth than those from set (2), but no appreciable difference in vigour was noticed in seedlings developed from embryos of the normal seeds, i.e., set (3), and those from set (2), unlike the previous experiment when the usual germination-test method was employed.

After the germination count, the cultures were kept under the laboratory conditions for a couple of days within which time the seedlings developed chlorophyll. The seedlings were then transferred to the liquid medium, that is, the same medium without the agar, and then to sand to which the liquid medium was added, and finally to soil in pots. All these transfers were done within three days. This process of gradual exposure to the normal field conditions from the artificial conditions was done in order to expose the seedlings gradually to the environmental conditions and to guard against the drying out of the seedlings during and after transplantation.

After transplantation, growth and development of the plants were observed, height was measured at regular intervals, total number of leaves produced was counted, and the date of flowering was noted. The data are tabulated in Table II.

TABLE I.
Germination test.

Column 1	2	3	4
Set (1)	40	75	35
" (2)	75	95	20
" (3)	100	100	nil

Percentage of germination by:—

Column 2:—usual method; column 3:—embryo-culture method; and column 4:—increase in the percentage of germination obtained by embryo-culture method over that obtained by usual method.

TABLE II.

Absolute seed weight and the growth and development of plants.

Set	Absolute seed-wt. (in gm.) (A)	Average height of plants (in cm.)				Increase in height between			Growth rate (B/A)	Total number of leaves produced	Number of days to flower
		30th day	60th day	90th day	110th day (B)	a	b	c			
(1)	40	6.0	12.0	17.0	18.0	6	5	1	0.45	7	106
(2)	100	17.0	36.0	51.0	59.0	19	15	8	0.59	13	103
(3)	155	18.0	40.0	65.0	67.0	22	25	2	0.43	13	85

a:—30th to 60th day; b:—60th to 90th day; and c:—90th to 110th day.

DISCUSSION.

In the present investigation it was found that the germination percentage was much less in shrivelled seeds than in the normal ones. This finding confirms the results obtained by many others, like Larbaletrier, Sturtevant, and Sturtevant, Arthur and Golf, cited by Martin (1920), who studied the germination of unripe seeds and that of mutilated ones. The latter authors found a decrease in germination of 2 to 25 times by mutilating the kernels of bean and corn seeds. Thus, the amount of endosperm present in the seed, or in other words, the quantity in the source of nutrient supply to the embryo determines, to a considerable extent, the germinating capacity of the seeds. The increase in the germination percentage that was obtained in the present investigation, when the embryos were separated out of the shrivelled seeds and were cultured in artificial nutrient medium, is a sufficient indication of the fact that the environment produced by the shrivelled grain is unfavourable for the normal functioning of the embryo, and that under-nourishment of the embryo due to the premature drying of the seeds, together with the unfavourable surroundings, made the embryos, that were potentially capable of germination, to behave as 'dead'. This point raises a question as to whether the percentage of germination, as expressed by the seed analyst in the seed-testing reports, is representative of the sample of the seed, as this percentage of germination does not take into account the shrivelled seeds, the majority of which are potentially capable of germination, and some of which can germinate even under usual conditions.

Kidd and West (1919), reporting on seed corn, referred to the differences in vigour of plants developed from immature seeds although they pointed out that there was no decrease in yield owing to the use of immature seeds. Harlan and Pope (1922), working with barley, also found that tallness and vigour of the plants decreased steadily with the decrease in the age of the seeds used, that is, the vigour of the plants would be less if the seeds used were younger and *vice versa*. LaRue (1936), reporting on the growth of the embryos *in vitro*, stated that the growth of the embryos was directly correlated with the size of the seeds of maize. Lofland (1950) also found similar results in cotton embryos, where embryos separated from 27-day old seeds grew more rapidly than those from 20-day old ones, and those from 15-day old seeds usually failed to grow. Kent, Brink, Graf, and Stahman (1950) showed that seedlings developed from immature embryos of rye *in vitro* were weaker than those from mature ones. Hatcher and Purvis (1945), however, did not find any decrease in the vigour of winter rye plants in relation to the maturity of the seeds used, and stated that there was no effect of the seed-weight on the vegetative growth of the plants. They also concluded that 'the higher efficiency of growth in plants from dwarf grain is a general phenomena among the cereal varieties studied.' The growth-rate was defined by them as the ratio of the final

weight of the plants to the initial weight of the embryo. From a study of the vegetative growth of 'Petkus' winter rye plants developed from seeds varying in weight from 2.3 to 36.3 mgm., Nutman (1941) found that the seed-weight had a correlation with the embryo-weight. Vasudeva and Dutt (1949) found that plants developed from the shrivelled wheat seeds caused by wheat rust, having a germination percentage of more than 70, behaved similar to those from normal seeds with regard to vigour of growth and yield. The seeds used could be classified as 'medium-shrivelled' seeds.

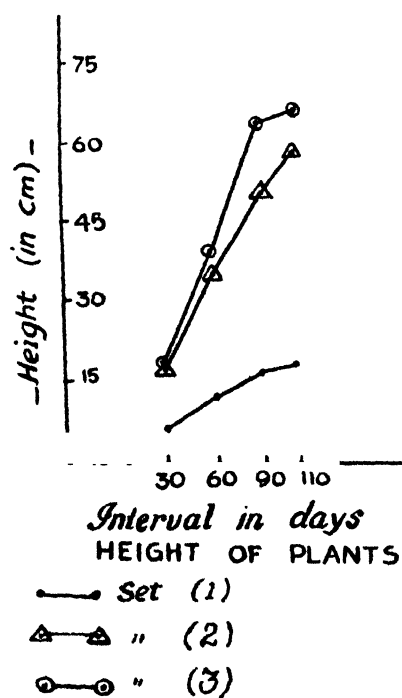
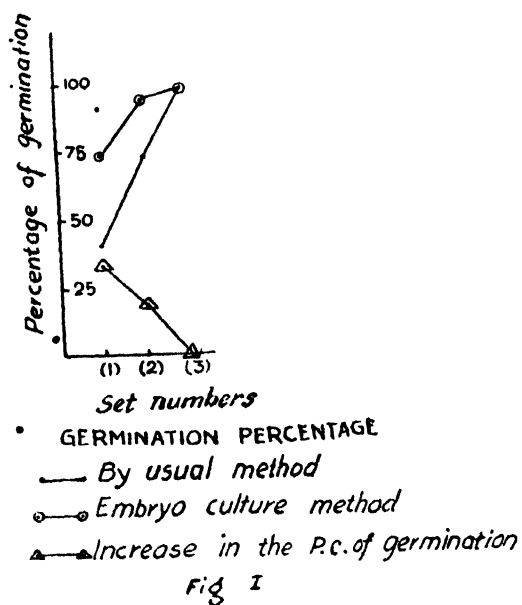
In the present investigation, it was found that there was a decrease in the vigour of plants developed from shrivelled grains, and this decrease was noticeable at every stage of growth of the plants. It was noticed in seedlings developed from shrivelled seeds, as also from embryos of such seeds in cultures, as well as in plants grown in soil under normal environmental conditions. The amount of decrease in vigour as measured by the height of the plants at different stages of growth and the total number of leaves produced, were more prominent in plants developed from very shrivelled seeds, i.e., set (1), than from the medium-shrivelled seeds and the normal ones, i.e., sets (2) and (3). This finding corroborates that of Kidd and West (1919), Harlan and Pope (1922), Kent, Brink, Graf and Stahman (1950) and others, but disagrees to a certain extent with that of Hatcher and Purvis (1945). Due to the lack of data regarding the embryo-weight, growth-rate, as defined by Hatcher and Purvis (1945) could not be calculated. Taking into consideration the fact that the embryo-weight is correlated with the seed-weight, a modified definition of the growth-rate may be given, and seed-weight and the total height reached by the plant may be taken into account in this respect. The ratio obtained, according to the new formula, of the growth-rate, was higher in case of shrivelled seeds than in normal ones, although it was not directly correlated with the degree of shrivelling of seeds. This conclusion, although obtained in a different way, agrees with that of Hatcher and Purvis (1945).

Delay in the flowering of the plants obtained from the embryos of shrivelled seeds, as found by the author, confirms the findings of Hatcher and Purvis (1945) who recorded that delay in flowering due to grain size was statistically significant. It also corroborates the findings of Gregory and Purvis (1938) who state that spring rye plants developed from immature seeds, collected from ears 11 days after anthesis, flowered 10.9 days later than those developed from normal grains, and that there was a progressive decrease in the flowering time with the progressively mature seeds used.

The fact that seedlings developed in cultures from embryos of very shrivelled seeds were much less vigorous than those of the medium-shrivelled or the normal seeds, suggests that response to the culture medium was progressively higher as the embryos were excised from the progressively mature seeds. Haagen-Smit, Siu, and Wilson (1945) also found in corn that the smaller the embryo, the lesser was its response to the culture medium.

Although the plants were developed by embryo-culture method in the present investigation, they compared well with the plants grown from mature and full seeds that have been reported by Gregory and Purvis (1938), Hatcher and Purvis (1945) and others.

Considering all the above facts, it is evident that in maize the shrivelled or immature seeds lead to a decrease in the vigour of plants developed from them, and the use of such shrivelled seeds for sowing purposes is not to be recommended. Kidd and West (1919) and Sumakova (1949) also emphasise the necessity of sowing sound and mature grains, and the latter author attribute better germination capacity, hardness, resistance to bunt, and higher yield to the use of larger sized seeds having higher seed-weight. Lastly, it may be emphasised that the germination-test, as is usually used by seed analysts in seed testing stations, is above any question as to its reliability, as, the seeds that are shrivelled are considered to be 'bad seeds'



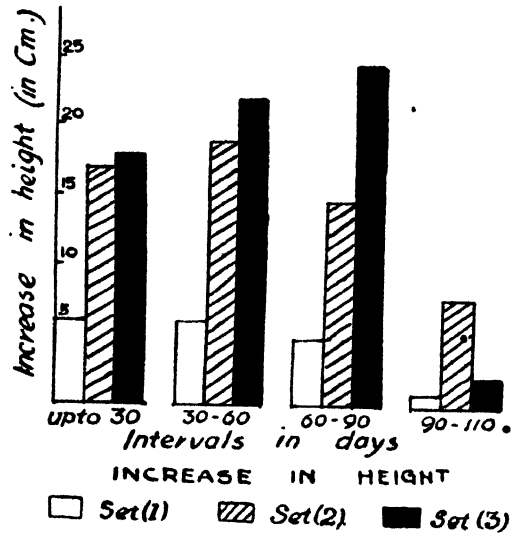


Fig. III

Normal Seeds



Shrivelled Seeds



Medium - Shrivelled



Very - Shrivelled

MAIZE

FIG. IV

Comparative sizes of the seeds according to the degree of shrivelling.

and are not taken into account for germination-test, although there may be quite a high proportion of them that are potentially capable of germination.

SUMMARY.

1. Seeds of red maize, obtained from local vendors during seed testing work, were graded into three sets according to their degree of shrivelling, as indicated by their absolute weights, viz., seed weight in set (1) 20 to 60 gms., set (2) 80 to 120 gms., and set (3) normal seed weight 155 gms.

2. Germination test was done by employing the usual germination method, and embryo-culture method. It was found that germination percentage decreased with the degree of shrivelling of seeds, and that embryo-culturing increased the germination percentage for the respective sets by an appreciable amount.

3. Seedlings, developed from the shrivelled seeds as well as those from the embryos, were weaker in growth and more glunder than those from the normal seeds or from the embryos of the same, and also that the greater the degree of shrivelling of the seeds the lesser was the vigour of plants developed from the embryos of such seeds. The delay in flowering was also directly correlated with the degree of shrivelling of seeds.

4. Growth-rate was found to be higher in case of plants developed from the shrivelled seeds than those from the normal seeds.

5. Due to the fact that plants developed from shrivelled seeds are less vigorous, more slender, and later in flower-production, and that the seeds have lesser germination capacity than the normal seeds, the method of germination-test as employed in the Seed Testing Stations, is quite justified and shrivelled seeds may safely be discarded from the sample for germination-test.

ACKNOWLEDGMENT.

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MORTALITY OF CARP FRY UNDER SUPERSATURATION OF DISSOLVED OXYGEN IN WATER.*

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(Communicated by Dr. T. J. Job, F.N.I.)

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INTRODUCTION.

Mortality of fish due to gas disease is not uncommon (Marsh and Gorham, 1905), and in certain cases it has been ascribed to excess of dissolved oxygen in water (Weibe, 1933; Woodbury, 1941, Haempel, 1928; Plehn, 1924). During experiments on rearing carp fry in the laboratory, it was observed on several occasions that when excessive algal bloom appeared in the aquaria the fish fry began to develop gas trouble and die in fair numbers. As such occurrence is possible in nurseries also, the phenomenon was studied in detail and the results are given below.

FISH AFFECTED.

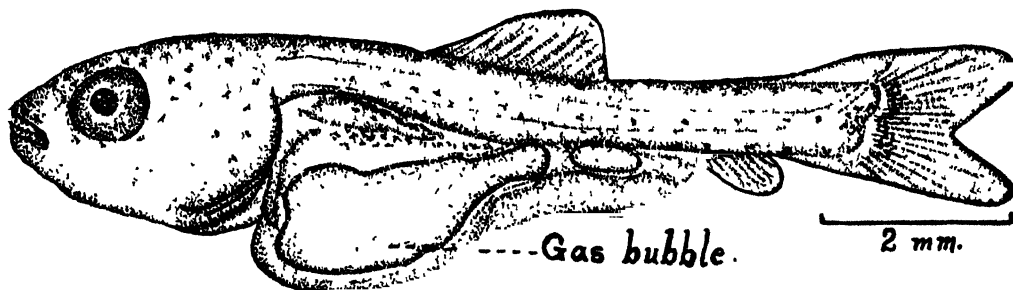
Mixed collections of carp fry, 5 mm. to 7 mm. long, were being reared in the jars. These contained *Catla catla*, *Labco rohita*, *L. calbasu*, *L. bata*, *Cirrhina mrigala* and *C. reba*. Specimens up to 20 mm. in length were affected by the gas disease (larger specimens were not present in the aquaria). About 70% of the affected fry were *L. calbasu*, though the species constituted only about 20% in the total collection.

SYMPTOMS OF DISEASE.

In the early stages of distress the fry were usually seen with scattered minute gas bubbles on the lower lip, and sometimes on the edges of the dorsal and caudal fins. Microscopic examination, however, did not show any obvious damage to the fin membrane. There was no bubble visible in the stomach and the fry were swimming normally. In the later stages gas began to accumulate in the stomach. While the fry had not lost equilibrium at this stage, owing to the presence of gas inside, it was constantly, though slowly, being buoyed up and was, therefore, swimming at

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an angle of about 45° , with the head pointing down. With continued accumulation of gas it could maintain equilibrium only by continuous effort. During advanced stages of distress the gas bubble in the stomach was quite conspicuous, even extending to the anterior half of the intestine (Fig. 1). The fry by now lost equilibrium and the gas bubble buoyed it up helplessly to the surface, where it was floating either on the side or with the belly up. The margin of the caudal, anal and dorsal fins had a blistered appearance and usually the membranous tissue had sloughed away, leaving the tips of fin rays exposed. When floating at the surface, for all practical purposes the fry appeared as dead, but when attempt was made to pipette them out they suddenly became active and vigorously swam down; however, in spite of repeated efforts they were soon buoyed up to the surface again. Continued accumulation of gas further distended the stomach and intestine and ended fatally to the young fish.



TEXT-FIG. 1: Carp Fry (*Cirrhina reba*), 10.5 mm. long, in advanced stage of gas trouble. Camera lucida sketch of specimen preserved in 5% formalin.

On one occasion some small gobies kept in a jar with water containing a thick algal bloom were also affected by similar gas trouble. As the day advanced and the jar was exposed to sun, gas began to accumulate as a conspicuous bubble, subcutaneously at the nape and also between the eye ball and the conjunctiva. In some specimens the operculum on either side was raised up by accumulated gas. The reactions of the fish were the same as those of the carp fry, first swimming at an angle and then floating up at surface, in a helpless manner.

CONDITIONS OF ENVIRONMENT.

Fifty carp fry were being reared in each of ten jars, containing about 3 litres of water. No sand or mud was provided at the bottom, and the water was not renewed after introduction of fry. The fry were fed daily with live plankton and the debris accumulating were regularly removed. The jars were placed in such a position that they were directly exposed to the sun daily for about three hours in the morning. Under these conditions, within a month, the water in all the jars developed thick algal blooms. Common forms like *Ankistrodesmus*, *Tetraspora*, *Microcystis*, *Merismopedia* and *Scenedesmus* constituted the dominant organisms in the bloom. Analysis of water samples showed excess of dissolved oxygen, ranging from 17.74 p.p.m. to 23.14 p.p.m., representing a maximum saturation of about 308%. The pH of the water was uniformly over 11.0. The diurnal fluctuations in the pH and dissolved oxygen content of water in these jars ranged from 9.5 and 8.63 p.p.m. respectively at 6 a.m. to over 11.0 and about 23.0 p.p.m. at 2 p.m. In the jar in which the gobies were kept the physico-chemical conditions were as follows:

Temperature, 32.0°C .; pH, over 11.0; Dissolved oxygen, 26.0 p.p.m.; Percentage of saturation of dissolved oxygen, 346%; Carbonates, 104 p.p.m., and Bicarbonates, 16.0 p.p.m.

CAUSES OF DEATH.

Death was apparently due to extreme distension of the stomach by continued accumulation of gas inside and the resulting state of congestion and choking. In some cases the accumulation of gas was to such an extent as to cause bursting of the stomach. The gas concerned was presumably oxygen. It is obvious that owing to the algal bloom there will be intense photosynthetic activity when the jars are exposed to the sun's rays. The resulting excess of dissolved oxygen will supersaturate the water and owing to difference in the oxygen tensions of water and the blood, the gas will diffuse into the blood stream of the fry. As mentioned by Marsh and Gorham (*loc. cit.*), under conditions of supersaturation of oxygen it is possible that direct osmosis of the gas between water and the tissues of the young fry might also take place. The symptoms of the trouble became manifest only as the day advanced, and when photosynthetic activity became intense, the fry were in acute distress.

In a similar case of fish mortality Woodbury (1941) has pointed out that slight changes in the conditions of existence like sudden rise in temperature of the body, might be sufficient to release part of the oxygen from the blood and tissues. In the present case, the fact that distress is acute when the oxygen tension in the water is constantly on the increase, probably shows that the release of oxygen from the blood and tissues is not due to lower oxygen tension in the surrounding medium. It is likely that during active photosynthesis the rapid increase in the dissolved oxygen content of water results in maintaining a continued disparity in the oxygen tension of that medium and the blood in the body of the fry. The saturation of oxygen in water is perhaps greater than the maximum oxygen-carrying capacity of blood, but owing to the inequality in tensions, the gas will continue to diffuse into the latter. The fry has to remove this excess gas from the blood and tissues but as the water is already highly supersaturated with oxygen, the gas cannot escape into that medium. This excess of oxygen, therefore, probably bubbles out into convenient body spaces like stomach, subcutaneous spaces, etc. According to Marsh and Gorham (*loc. cit.*) it is even 'probable that the metabolic functional disturbance due to the abnormal osmosis is itself sufficient to cause death without apparent gas symptoms'.

It is interesting to note in this connection that fry in advanced stages of distress, when transferred to fresh pond water, devoid of any algal bloom, slowly revived and became normal within about 6 hours. The bubble gradually disappeared from the stomach and the fry, regaining equilibrium, began to move about normally. The small gobies also recovered when similarly treated.

GENERAL REMARKS.

Out of the mixed collection of carp fry in the experimental jars, *L. calbasu* was most severely affected by the gas disease. *C. catla* and *L. rohita* were not so numerous as the other species, and they were not observed to be easily affected. While it is known that susceptibility varies with the species as well as their stage and size, it is not at present possible to state clearly why fry of *L. calbasu* were the worst affected. The possibility of a greater extent of direct osmosis than in other species and also possible differences in the relative volume of blood and its oxygen-carrying capacity, might be among the factors that contributed to the acute distress in *L. calbasu*.

The mortality resulting from the gas trouble described above has a direct bearing on the survival of carp fry stocked in nursery ponds. It is the general practice to manure the nurseries heavily before introduction of fry; and this, not uncommonly, results in the production of algal blooms in water. The supersaturation of dissolved oxygen in water owing to heavy algal blooms in nurseries has been found to be

sometimes higher than that observed in the experimental jars. In one of the nurseries at the Killa, Cuttack, at a water temperature of 33.1°C ., the pH was over 11.0 and the dissolved oxygen content was 24.3 p.p.m. This represents a saturation of dissolved oxygen to about 323 per cent. It is quite probable that the delicate carp fry when introduced into the pond under such conditions, will be adversely affected. But, even when the gas trouble is acute and a number of fry are affected it will be relatively difficult to detect them in the natural pond as they will be floating inconspicuously near the margin, amidst weeds. Even in the experimental jars the affected fry were very inconspicuous, although they were floating at the surface. In the light of the above observation, it will be necessary to maintain careful watch over the conditions of water in the pond, and if gas trouble is detected the affected fry could be rescued by transferring them to fresh water. However, judicious methods of manuring the pond so as to ensure a moderate density of plankton over a protracted period might be an effective preventive against such occurrences.

In the experimental jars the appearance of algal blooms can be prevented if the water is renewed at weekly intervals. In experiments where the water is not to be changed after introduction of fry, the jars have to be kept in shade where they will not ordinarily be exposed to direct rays of the sun. When algal bloom is existing in water, mechanical agitation will help to remove some of the excess gas and bring down the supersaturation.

ACKNOWLEDGEMENTS.

The observations recorded in this note were made when we were investigating the causes of the excessive mortality of carp fry in nursery ponds at Cuttack. We are indebted to Sri G. N. Mitra for kindly providing us facilities for carrying out the observations. Our grateful thanks are due to Dr. T. J. Job for his very helpful criticisms and suggestions in the preparation of this note.

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PECTIN-ESTERASE OF DRUMSTICK LEAVES

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INTRODUCTION.

Among leafy sources, *Solanaceae* have high pectin-esterase content (Holden, 1946); others that have been reported include alfalfa (Mehlitz, 1930; Lineweaver and Ballou, 1945) and clover (Davison and Willaman, 1927; Tzerevitinov and Rozanova, 1934). It is shown in this communication that although drumstick (*Moringa pterygosperma*) leaf is not as rich a source of the enzyme as tomato pulp (Kertesz, 1937 and 1938; Pithawala *et al.*, 1948) or citrus peel (Mac Donnell *et al.*, 1945), it is comparable in this respect to leafy sources other than *Solanaceae* (Holden, 1946); important differences in the properties of the enzyme in relation to its source are also brought out.

EXPERIMENTAL.

Measurement of activity.

Activity measurements were carried out as detailed previously (Pithawala *et al.*, 1948) by colorimetric determination of methanol liberated in 10 minutes from buffer-substrate consisting of 5 c.c. of 0.8% pectin solution and 5 c.c. of 0.1M Na₂HPO₄ at pH 8, using 0.1—1 c.c. of the enzyme solution. Corrections were made for non-enzymic demethylation by carrying out tests without the addition of enzyme. One unit of enzyme represents that amount which would liberate 32 mg. of methanol from pectin in 1 minute, under these conditions at 27°C. ($\pm 1^\circ$).

Location of activity.

The fresh leaves were minced in a mortar and squeezed with hand through muslin, 50 g. of the leaves giving approximately 24 g. of wet weight of fibres. The distribution of enzyme in the sap before and after centrifuging and in the fibres after extraction with 1:5 0.1M Na₂HPO₄ at pH 8 for 2 hours are given in Table I.

TABLE I.
Location of Activity.

	Activity units per g. of				% of total activity in		
	Leaf.	Fibre.	Sap.	Centri-fuged sap.	Fibre.	Sap.	Centri-fuged sap.
Coarsely minced	0.004113	0.0061	0.00228	0.00147	71.17	28.83	17.86
Finely minced ..	0.0192	0.0372	0.00259	0.00144	92.9	7.1	3.9

The enzyme in the sap was to a great extent associated with the cell debris removable by centrifugation. The activity varied between 0.0358 and 0.0546 units per g. fibre in different batches and was not appreciably different in young and old leaves.

Extraction.

In Table II are given the results of extraction of fibre at different pH and salt concentrations.

TABLE II.
Effect of salt and pH on extraction.

Extractant and pH			pH of extract	Activity units per c.c. of extract.	Relative activity per cent.
(i) <i>Effect of salt concentration:</i>					
Water		7.5	5.5	0.00234	44.0
0.1 M NaCl		7.0	5.5	0.00291	54.8
0.2 M "		7.0	5.5	0.00375	70.6
0.5 M "		7.0	5.5	0.00493	92.8
1.0 M "		7.0	5.5	0.00531	100.0
2.0 M "		7.0	5.5	0.00522	98.3
(ii) <i>Effect of pH:</i>					
2 M Na ₂ HPO ₄	5.0		5.0	0.00194	20.7
2 M "	6.0		6.0	0.00234	24.9
2 M "	7.0		7.0	0.00706	75.3
2 M "	8.0		8.0	0.00937	100.0
2 M NaCl	8.0		5.5	0.00806	86.0

Extraction of enzyme was best at pH 8 and increased with salt concentration; use of Na₂HPO₄ gave better yield than NaCl, due to its buffering action.

The activities of two successive extracts obtained by soaking the finely minced fibres for 2 hours with phosphate buffer at pH 8.0 were respectively 71.6 and 28.4 per cent. of the total. For the following experiments, the minced fibres were extracted with 1:10 weight/volume of 0.1 M Na₂HPO₄ at pH 8 and centrifuged at 3,000 r.p.m. for 15 minutes. The extract had an activity of 0.002625 units per c.c. and kept well when stored in the ice chest.

Partial purification of the enzyme.

A known volume of the enzyme solution (100 c.c.) was serially precipitated with increasing additions of ammonium sulphate. The precipitates obtained after centrifuging at each stage were dissolved in phosphate buffer (20 c.c.) at pH 8 and their activities determined (Fig. 1). For comparison, the results obtained by fractional precipitation with alcohol are included. Ethanol precipitation resulted in complete loss of activity; precipitations in the cold were not attempted (cf. Neuberg and Kobel, 1927; Mehlitz, 1930; Lineweaver and Ballou, 1945).

Addition of ammonium sulphate did not appreciably lower the pH of the phosphate solution on account of the latter's buffering capacity; the maximum pH

change was from 8 to 6, which was well outside the point of inactivation. The results included in (Fig. 1) show that between 40 and 60 per cent concentrations of ammonium sulphate, most of the enzyme was precipitated, more than 40 per cent. of the original activity being obtained at 60 per cent. concentration.

Precipitation at 60 per cent concentration of ammonium sulphate, after discarding the precipitate obtained at 30 per cent concentration, gave a product with about 55 per cent. of the original activity. This was further purified by a second salting out with ammonium sulphate in the same manner as above, when a preparation was obtained retaining only 32 per cent of the enzyme originally present but with an activity of 0.00348 units per mg. dry weight as compared with 0.0000363 units in the original extract or representing a 90-fold concentration of the enzyme. The product could be dried *in vacuo* at room temperature without loss in activity, the yield being about 10 mg. per 100 c.c. of the original extract.

For the following experiments, a preparation purified as above was used, the final precipitate from 100 c.c. of the extract being dissolved in 50 c.c. of the phosphate buffer at pH 8.

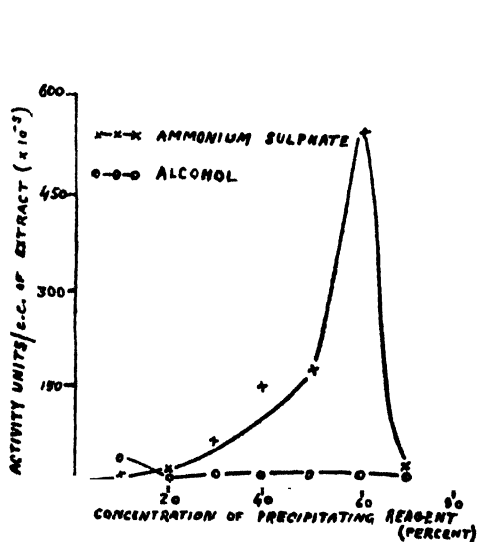


FIG. 1. Fractional Precipitation of the Enzyme.

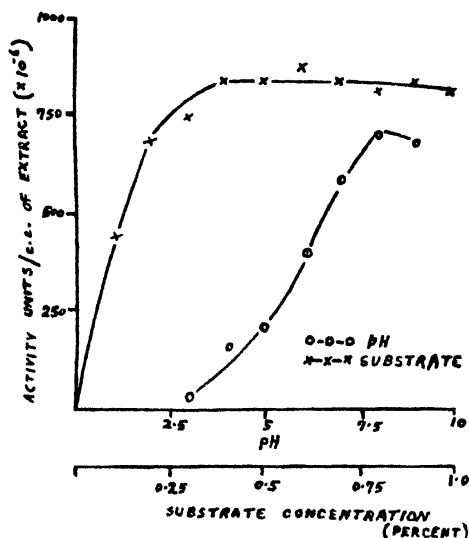


FIG. 2. Variation of Activity with pH and Substrate Concentration.

Properties of the enzyme.

The effects of variations in activity with pH, time, enzyme concentration, substrate concentration and temperature are given in Figs. 2 to 4. The dialyzed enzyme solution was used only for activity pH tests; in other cases it was diluted to half concentration.

Activity was maximum at pH 8 (Fig. 2) which agrees closely with that of tobacco pectin-esterase (Holden, 1946). The relationships between activity and time or enzyme concentration were linear for first 20 minutes' de-esterification and for lower concentrations of enzyme employed (Fig. 3). Activity increased with substrate concentration up to 0.4% (Fig. 2). The concentration of pectin which gave half the maximum velocity of hydrolysis was about 0.095–0.1%. The optimum temperature for activity was 45–50°C. for 10 minutes' reaction time (Fig. 4) and was nearly the same as for tomato pectin-esterase. Non-enzymic demethylation was appreciable above 30°C.

Stability of the enzyme.

(i) *Effect of pH.*—The effects of pH on the stability of drumstick pectin-esterase at 4°C. and at room temperature are shown in Fig. 5. The tests were made by adding to the dialyzed enzyme extract an equal volume of different buffers and keeping for one week. The enzyme was stable near natural pH of the leaf tissue, viz. pH 5.5. (Fig. 5). Since some of the enzyme is precipitated below pH 5, the loss may not be as much as indicated.

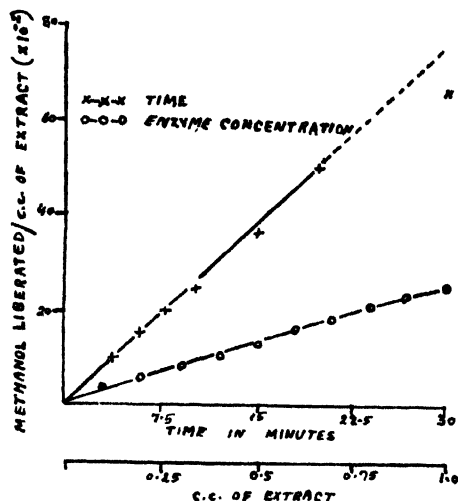


FIG. 3. Variation of Activity with time and Enzyme Concentration.

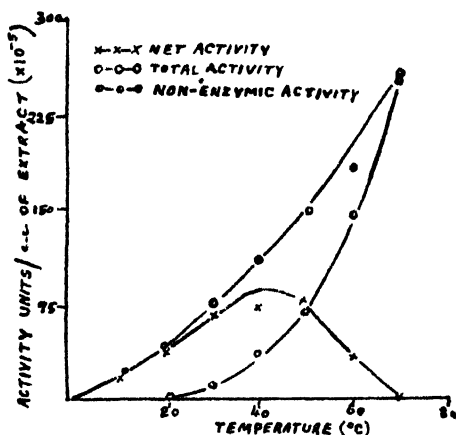


FIG. 4. Variation of Activity with Temperature.

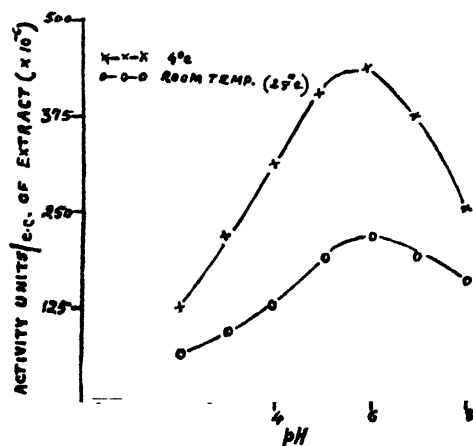


FIG. 5. Stability of Enzyme with pH.

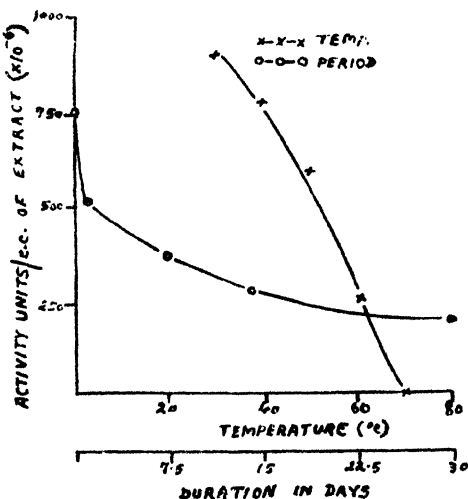


FIG. 6. Stability of Enzyme with Temperature and after Dialysis.

(ii) *Effect of temperature.*—The enzyme extract was maintained at different temperatures for 5 minutes before activity determinations were made. The enzyme was inactivated completely at 70°C. (Fig. 6); the time for destruction at this temperature was less than a minute. The enzyme therefore differs from tomato pectin-esterase

(Pithawala *et al.*, 1948) where presumably the salts present offered better protection against thermal inactivation than here.

(iii) *Effect of dialysis.*—The stabilizing effect of the salts on pectin-esterase extract was interable from the rapid loss in activity of the dialysed extract on standing (Fig. 6).

Adsorption of pectin-esterase.

The adsorption of drumstick pectin-esterase was studied with different adsorbents using an aqueous solution of a partially purified enzyme preparation dialysed for six hours. A known quantity of adsorbent (10 mg. per c.c. of extract) was shaken with the extract for 10 minutes and the activity of the supernatant was determined after centrifuging (Table III).

TABLE III.
Adsorption of drumstick pectin-esterase.

(i) Use of different adsorbents at natural pH of extract:

Adsorbent ..	Kieselguhr.	Alumina.	Kaolin.	Fuller's earth.	Hyflo supercel.	Charcoal.
Per cent of original activity in supernatant ..	79.3	77.5	94.5	86.6	96.3	81.2

(ii) Effect of pH on adsorption on alumina:

pH	4	5	6	7	8	9	10
Per cent of original activity in supernatant ..	75.03	75.03	90.00	93.75	101.10	101.1	101.1

Adsorption was better on charcoal, Kieselguhr and alumina, though only a small part of the enzyme was adsorbed. The effect of pH on the adsorption of the enzyme on alumina was studied using 2 c.c. of the aqueous enzyme solution, 8 c.c. of buffer at different pH values and 5 c.c. of alumina suspension (5 mg. per c.c.). The mixture was shaken for 10 minutes and the activity determined on the supernatant after centrifuging. The enzyme was best adsorbed at lower pH values (pH 4 to 5 in this case); there was no adsorption at all at higher pH values. Successive use of alumina at pH 4 showed 24 and 3 per cent. adsorption in the first and second treatment respectively.

DISCUSSION.

The studies reported here emphasise the differences in properties of pectin-esterase from various sources. Drumstick leaf, like other leafy sources, excepting *Solanaceae*, is poor in pectin-esterase (0.016 to 0.020 unit/g.) when compared to tomato pulp (0.30 to 0.35 unit/g.) or citrus peel (0.060 to 0.075 unit/g.); the enzyme content is also rather less than that of *Solanaceae* (0.015 to 0.03 unit/g.) Holden, (1946). Drumstick pectin-esterase resembles tomato pectin-esterase in many of its properties (Pithawala *et al.*, 1948) but differs chiefly in its stability against temperature and pH. The enzyme is inactivated to a greater extent than tomato pectin-esterase

during precipitation with ammonium sulphate and requires higher concentration for complete precipitation from solution. Further longer periods of soaking as well as mincing are necessary for complete extraction of the enzyme from leaf tissues. The enzyme also differs from citrus and tobacco pectin-esterase in its optimum temperature as well as in its thermal stability and pH. Quantitative differences in properties of pectin-esterase from plant tissues and particularly from moulds have been pointed out by a few workers (Hills and Mottern, 1947; McColloch and Kertesz, 1947). In view of the fact that a partially purified preparation has been used for these studies, it is unlikely that such differences in the properties of pectin-esterase from plant tissues are attributable to congeneric impurities. The importance of cations and salt concentration (Lineweaver and Ballou, 1945; MacDonnell *et al.*, 1945) in the enzyme extract and in the substrates are additional factors to be reckoned with.

SUMMARY.

1. Pectin-esterase activity in drumstick leaf was determined by estimation of the amount of methanol liberated from pectin under standard conditions.
2. The enzyme is mainly associated with the fibres, the sap containing little activity; the extraction of the enzyme from the fibres is influenced by pH, salt concentration and the degree of mincing and is best done at pH 8 with phosphate buffer.
3. An active enzyme concentrate or a dry preparation can be obtained by precipitating the enzyme with 60 per cent concentration of ammonium sulphate, after discarding the initial precipitate at 30 per cent concentration of salt.
4. The optimum conditions for enzyme activity were found to be pH 8 and 50°C. for 10 minutes' reaction time. The enzyme is most stable near natural pH of the leaf tissue. At 70°C. it is completely inactivated.
5. The enzyme is adsorbed on charcoal, alumina and Kieselguhr, adsorption being influenced by the presence of salts and pH of the extract.

ACKNOWLEDGEMENT.

Acknowledgement is made to the Provincial Industrial Research Committee of the Bombay Government, Department of Industries, for a research grant in support of this investigation.

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SOME FORMULAE OF SPHERICAL ASTRONOMY OBTAINED BY TENSOR METHOD.

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1. INTRODUCTION.

The use of tensor methods in obtaining the effect of geocentric parallax on the declination and right ascension of the moon or a planet is already known. (Jeffreys, 1950). The object of this paper is to extend the method of tensors to obtain expressions for the changes in latitude and longitude, right ascension and declination of a star due to (i) annual parallax, and (ii) aberration.

2. ANNUAL PARALLAX.

Take the origin at the centre of the earth, axis of x towards the first point of Aries, axis of y towards the point on the ecliptic which is 90 degrees ahead of γ and the axis of z towards the pole of the ecliptic. Let the co-ordinates of the star be $x_i = r'l_i$, and those of the sun be $\xi_i = a\lambda_i$. Let r be the distance between the sun and the star, then we have

$$r^2 = (x_i - \xi_i)^2 = r'^2 - 2r'al_i\lambda_i + a^2,$$

or
$$r = r' - al_i\lambda_i, \text{ to the first order of } \frac{a}{r'}. \quad (1)$$

Thus $r' = r + al_k\lambda_k$, changing the dummy affix i to k .

Let \bar{l}_i be the direction cosines of the line joining the centre of the sun to the centre of the star. Then

$$\bar{l}_i = \frac{x_i - \xi_i}{r} = \frac{r'l_i - a\lambda_i}{r} = \frac{(r + al_k\lambda_k)l_i - a\lambda_i}{r}$$

or
$$\bar{l}_i = l_i + \pi(l_k\lambda_k l_i - \lambda_i) \quad \dots \quad (2)$$

where $\pi \left(= \frac{a}{r} \right)$ is the annual parallax of the star.

Now the direction cosines are given in terms of the angular co-ordinates by

$$\left. \begin{aligned} l_1 &= \cos \beta \cos \lambda, & l_2 &= \cos \beta \sin \lambda, & l_3 &= \sin \beta, \\ \lambda_1 &= \cos \odot, & \lambda_2 &= \sin \odot, & \lambda_3 &= 0 \end{aligned} \right\} \quad \dots \quad (3)$$

where \odot is the longitude of the sun and λ, β are respectively the longitude and latitude of the star.

Also
$$l_k\lambda_k = \cos \beta \cos (\odot - \lambda) \quad \dots \quad (4)$$

For the parallax in latitude, $\Delta\beta$,

$$\cos \beta \cdot \Delta\beta = l_3 - \bar{l}_3 = \pi(\lambda_3 - l_k\lambda_k l_3) = -\pi \cos \beta \cos (\odot - \lambda) \sin \beta$$

so that,
$$\Delta\beta = -\pi \sin \beta \cos (\odot - \lambda) \quad \dots \quad (5)$$

Again, $\tan \lambda = \frac{l_2}{l_1}$, $\therefore \log \tan \lambda = \log l_2 - \log l_1$

$$\begin{aligned} \text{or } \frac{\sec^2 \lambda}{\tan \lambda} \Delta \lambda &= \frac{l_2 - \bar{l}_2}{l_2} - \frac{l_1 - \bar{l}_1}{l_1} = \pi \left(\frac{\lambda_2}{l_2} - \frac{\lambda_1}{l_1} \right) \\ &= \frac{\pi}{\cos \beta} \left(\frac{\sin \odot}{\sin \lambda} - \frac{\cos \odot}{\cos \lambda} \right) = \frac{\pi}{\cos \beta \sin \lambda \cos \lambda} \sin (\odot - \lambda). \end{aligned}$$

$$\text{Hence } \Delta \lambda = \pi \sec \beta \sin (\odot - \lambda). \quad \dots \dots \dots (6)$$

COR. Expressing λ and β in terms of the right ascension α , the declination δ and the obliquity of the ecliptic ϵ , we have (Smart, 1931)

$$\begin{aligned} l_1 &= \cos \delta \cos \alpha, \quad l_2 = \sin \delta \sin \epsilon + \cos \delta \cos \epsilon \sin \alpha, \\ l_3 &= \sin \delta \cos \epsilon - \cos \delta \sin \epsilon \sin \alpha \quad \dots \dots \dots (7) \end{aligned}$$

$$\text{and } l_k \lambda_k = \cos \alpha \cos \delta \cos \odot + \sin \delta \sin \epsilon \sin \odot + \sin \alpha \cos \delta \cos \epsilon \sin \odot \quad \dots (8)$$

From (7) we have

$$\sin \delta = l_3 \cos \epsilon + l_2 \sin \epsilon \quad \dots \dots \dots (9)$$

$$\begin{aligned} \therefore \cos \delta \cdot \Delta \delta &= \cos \epsilon \cdot (l_3 - \bar{l}_3) + \sin \epsilon \cdot (l_2 - \bar{l}_2) \\ &= \pi \cos \epsilon (\lambda_3 - l_k \lambda_k l_3) + \pi \sin \epsilon (\lambda_2 - l_k \lambda_k l_2) \\ &= \pi \sin \epsilon \sin \odot - \pi \sin \delta (\cos \alpha \cos \delta \cos \odot + \sin \delta \sin \epsilon \sin \odot \\ &\quad + \sin \alpha \cos \delta \cos \epsilon \sin \odot) \end{aligned}$$

$$\text{Hence } \Delta \delta = \pi (\cos \delta \sin \epsilon \sin \odot - \cos \alpha \sin \delta \cos \odot - \sin \alpha \sin \delta \cos \epsilon \sin \odot) \quad \dots (10)$$

Again, from (7) $\cos \alpha \cos \delta = l_1$,

$$\sin \alpha \cos \delta = \frac{l_2 - \sin \delta \sin \epsilon}{\cos \epsilon} = \frac{l_2 - (l_3 \cos \epsilon + l_2 \sin \epsilon) \sin \epsilon}{\cos \epsilon} = l_2 \cos \epsilon - l_3 \sin \epsilon \quad \dots (11)$$

$$\therefore \tan \alpha = \frac{l_2 \cos \epsilon - l_3 \sin \epsilon}{l_1}, \quad \dots \dots \dots (12)$$

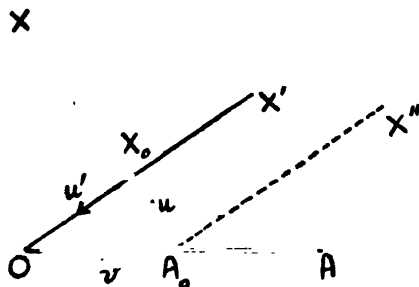
$$\log \tan \alpha = \log (l_2 \cos \epsilon - l_3 \sin \epsilon) - \log l_1$$

$$\begin{aligned} \therefore \frac{\sec^2 \alpha}{\tan \alpha} \cdot \Delta \alpha &= \frac{(l_2 - \bar{l}_2) \cos \epsilon - (l_3 - \bar{l}_3) \sin \epsilon}{l_2 \cos \epsilon - l_3 \sin \epsilon} - \frac{l_1 - \bar{l}_1}{l_1} \\ &= \frac{\pi (\lambda_2 \cos \epsilon - \lambda_3 \sin \epsilon) - \pi l_k \lambda_k (l_2 \cos \epsilon - l_3 \sin \epsilon)}{l_2 \cos \epsilon - l_3 \sin \epsilon} - \frac{\pi (\lambda_1 - l_k \lambda_k l_1)}{l_1} \\ &= \frac{\pi \cos \epsilon \sin \odot}{\sin \alpha \cos \delta} - \frac{\pi \cos \odot}{\cos \alpha \cos \delta}. \end{aligned}$$

$$\text{Hence } \Delta \alpha = \pi \sec \delta (\cos \alpha \cos \epsilon \sin \odot - \sin \alpha \cos \odot) \quad \dots \dots \dots (13)$$

3. ABERRATION.

Let X be the true position of a star, A the apex towards which the observer's motion is directed. Let v be the velocity of the observer and u the velocity of light. Along OA mark off length OA_0 to represent v and along XA_0 mark off the length X_0A_0 to represent u , then X_0O represents the velocity of light relative to the observer, say u' . Draw A_0X'' parallel to OX' . Then A_0X'' (or OX') is the apparent direction of the star while A_0X is the true direction.



Let the longitude and latitude of the star be λ and β respectively and let \odot be the longitude of the sun, so that the longitude of the apex is $\odot - 90^\circ$.

Let the co-ordinate axes be the same as in § 2. Let the co-ordinates of X_0 be $x_i = u'l_i$, and those of A_0 be $\xi_i = r\lambda_i$.

Then we have $u^2 = (x_i - \xi_i)^2 = u'^2 - 2u'l_k\lambda_k + r^2$

or $u = u' - r'l_k\lambda_k \quad \dots \quad (14)$

to the first order of $\frac{v}{u'}$. $\therefore u' = u + v'l_k\lambda_k \quad \dots \quad (14')$

Then the direction cosines of the line A_0X_0 are \bar{l}_i where

$$\bar{l}_i = \frac{x_i - \xi_i}{u} = \frac{u'l_i - r\lambda_i}{u} = \frac{(u + r'l_k\lambda_k)l_i - r\lambda_i}{u} = l_i + k(l_k\lambda_k - \lambda_i) \quad \dots \quad (15)$$

where $k \equiv \frac{v}{u}$, the constant of aberration.

Again the values of l_i are given by (3) or (7) while

$$\lambda_1 = \sin \odot, \lambda_2 = -\cos \odot, \lambda_3 = 0 \quad \dots \quad (16)$$

$$\therefore l_k\lambda_k = \cos \beta \sin (\odot - \lambda).$$

Let $\Delta\beta$ and $\Delta\lambda$ be the changes in latitude and longitude due to aberration, then we have $\cos \beta \cdot \Delta\beta = l_3 - \bar{l}_3 = k(\lambda_3 - l_k\lambda_k) = -k \cos \beta \sin \beta \sin (\odot - \lambda)$

or $\Delta\beta = -k \sin \beta \sin (\odot - \lambda) \quad \dots \quad (17)$

Also since $\tan \lambda = \frac{l_2}{l_1}$, we have, $\frac{\sec^2 \lambda}{\tan \lambda} \Delta\lambda = \frac{l_2 - \bar{l}_2}{l_2} - \frac{l_1 - \bar{l}_1}{l_1}$

$$= -\frac{k}{\cos \beta \sin \lambda \cos \lambda} \cos (\odot - \lambda)$$

$$\therefore \Delta\lambda = -k \sec \beta \cos (\odot - \lambda) \quad \dots \quad (18)$$

Again, using (9) we have $\cos \delta \cdot \Delta\delta = \cos \epsilon \cdot (l_3 - \bar{l}_3) + \sin \epsilon \cdot (l_2 - \bar{l}_2)$

$$\therefore \Delta\delta = -k \cos \odot \cos \epsilon (\tan \epsilon \cos \delta - \sin \alpha \sin \delta)$$

$$-k \cos \alpha \sin \delta \sin \odot, \quad (\text{from (15) and (16)}) \quad \dots \quad (19)$$

Also from (12) proceeding exactly as in §2 and using (15) and (16) we get

$$\Delta\alpha = -k \sec \delta (\cos \alpha \cos \odot \cos \epsilon + \sin \alpha \sin \odot) \quad \dots \quad (20)$$

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FLOWER STRUCTURE AND SEED DEVELOPMENT IN ISOTOMA FLUVIATILIS F.v.M.*

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(Communicated by Dr. P. Maheshwari, F.N.I.)

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INTRODUCTION.

According to Engler (1897) the genus *Isotoma* Lindl. belongs to the tribe Lobelioideae of the Campanulaceae, while Hutchinson (1926) places it in a separate family, Lobeliaceae, along with *Centropogon*, *Siphocampylus*, *Laurentia*, *Pratia*, *Lobelia* and *Cyphia*. It comprises 8 species recorded from Australia and the Society Islands. Kausik and Subramanyam (1945a, 1947b) have described the embryology of *I. longiflora*, and Rosén (1949) has studied the mode of endosperm formation in *I. axillaris*.

MATERIALS AND METHODS.

I. fluvialis, which is the object of the present study, is a slender herb, collections of which were very kindly made for me from the margins of some ponds between Windsor and Richmond in New South Wales, Australia, by Mr. O. D. Evans. The material was fixed in formalin-acetic-alcohol, dehydrated and embedded in paraffin in the usual manner, and sectioned at a thickness of 10 to 16 microns. The sections were stained in Heidenhain's iron alum Haematoxylin with eosin as a counterstain. Sections of the fruits were stained with safranin and light green.

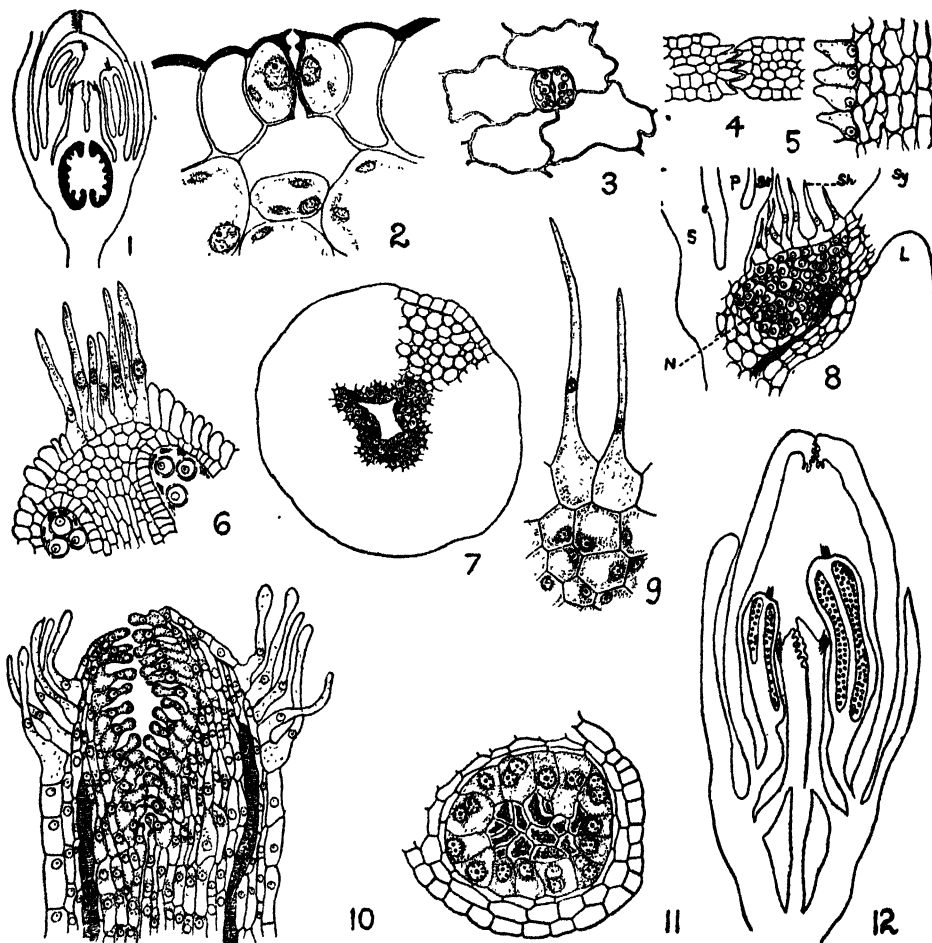
FLOWER.

The floral parts arise in acropetal succession: sepals, petals, stamens and carpels. Fig. 1 is a longitudinal section of a young flower bud showing the disposition of the different floral parts. The flowers are bracteate and pedicellate with two minute bracteoles. There are five sepals and five petals having a valvate aestivation. Stomata are present on the outer epidermis of both (Figs. 2, 3). The epidermal cells of adjacent petals present an interlocking arrangement (Fig. 4). Further, while the outer epidermis of each petal consists of rectangular cells, the cells of the inner epidermis are papillose with the nuclei situated close to their inner walls (Fig. 5).

There are five epipetalous stamens. The epidermal cells of the connective are drawn out into long unicellular hairs (Fig. 6) so that the apex of the stamen is quite hairy (Figs. 1, 6). The style is long and slender and bears a bilobed stigma. In transverse section the style is circular and has a slender styler canal (Fig. 7). The cells surrounding the canal are small and compactly arranged, with conspicuous nuclei and dense contents. This is the transmitting tissue. The epidermal cells of the stigma are nippleshaped and densely cytoplasmic (Fig. 10). Those around the apex of the style are drawn out into upwardly directed unicellular hairs forming

* Part of work done during the tenure of a Junior Research Fellowship of the National Institute of Sciences of India.

what may be called the stylar brush. In *Lobelia assurgens* (Rendle, 1938) and *L. erinus* (Knuth, 1909) it has been noted that as the style protrudes through the anther tube, the hairs of the stylar brush push out the pollen in the tube and are checked above by the stiff hairs on the top of the anthers. It is probable that the stylar brush and the hairs at the top of the anthers perform a similar function in the present form and are probably special adaptations for cross-pollination.



- FIG. 1. L.S. of young flower bud to show arrangement of floral parts. $\times 30$.
 FIG. 2. Section of stoma on outer epidermis of sepal. $\times 970$.
 FIG. 3. Surface view of stoma on outer epidermis of petal. $\times 310$.
 FIG. 4. Interlocking arrangement of adjacent petals. $\times 215$.
 FIG. 5. Portion of petal showing papillose inner epidermis. $\times 129$.
 FIG. 6. Unicellular hairs at the apex of the anther. $\times 129$.
 FIG. 7. T.S. of style. $\times 485$.
 FIG. 8. L.S. of nectary (L—Locule; N—Nectary; P—Petal; S—Sepal; Sh—Secretory hair; St—Stamen; Sy—Style). $\times 70$.
 FIG. 9. Portion of nectary enlarged. $\times 301$.
 FIG. 10. Bilobed stigma with papillose cells and stylar brush. $\times 129$.
 FIG. 11. Portion of cross-section of anther lobe showing degenerated pollen mother cells and enlarged tapetum. $\times 679$.
 FIG. 12. L.S. of flower showing absence of ovules in loculi; note pollen grains in anthers. $\times 30$.

Around the base of the style there is a prominent nectary (Fig. 8, *N*) consisting of glandular cells with conspicuous nuclei and vacuolate contents (Fig. 9). The epidermal cells of the nectary are modified into long slender, uninucleate secretory hairs (Figs. 8, 9).

MICROSPORANGIUM AND MALE GAMETOPHYTE.

A transverse section of the young anther lobe shows a plate of six to eight hypodermal archesporial cells which divide periclinally to form the primary parietal and primary sporogenous cells (Fig. 13). The cells of the primary parietal layer by further divisions form the anther wall consisting of the epidermis, endothecium, a middle layer, which soon becomes flattened and crushed, and the glandular tapetum (Figs. 14–16). The cells of the tapetum are uninucleate at first but later become binucleate (Fig. 16). The sporogenous cells undergo a few further divisions to form the spore mother cells. Seven bivalents were counted in a polar view of the first meiotic metaphase (Fig. 17). Quadripartition of the microspore mother cells takes place by cleavage furrows and the microspores are arranged tetrahedrally.

In the mature anther (Fig. 19), the tapetum and the middle layer completely disorganise and the endothecium develops the usual fibrous thickenings. The outer wall of the epidermal cells is thickly cutinised. In young stages the epidermal cells of adjacent anthers just touch one another (Fig. 18) but later they become interlocked (Fig. 19) and exhibit an almost syngenesious condition.

The nucleus in the young microspore is situated in the centre (Fig. 20). Soon, it moves towards the wall (Fig. 21) and divides (Fig. 22) to form a small lenticular

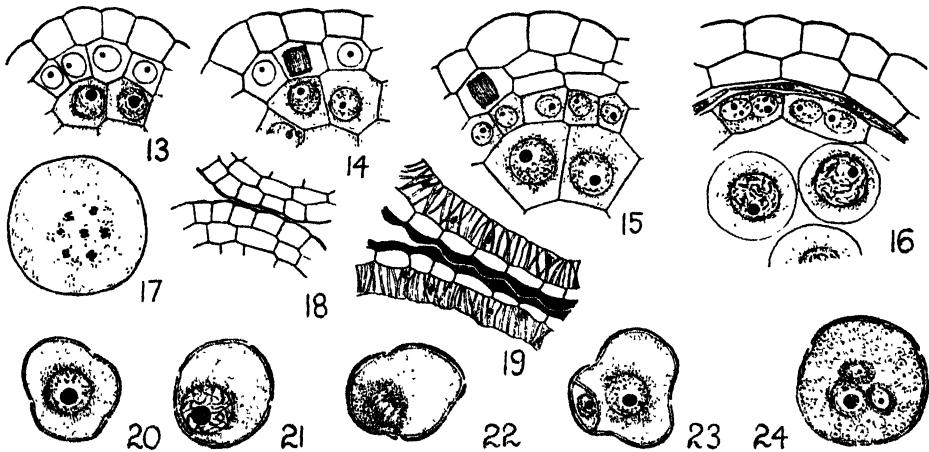


FIG. 13. Portion of anther lobe showing primary parietal layer and primary sporogenous layer. $\times 679$.

FIG. 14. Division of primary parietal layer. $\times 679$.

FIG. 15. Portion of young anther showing epidermis, endothecium, uninucleate tapetum and sporogenous cells. $\times 679$.

FIG. 16. Later stage showing binucleate tapetum and microspore mother cells. $\times 679$.

FIG. 17. Polar view of dividing mother cell showing seven bivalents. $\times 1455$.

FIG. 18. Anther walls of two young and adjacent anthers. $\times 430$.

FIG. 19. Same at a later stage showing fibrillar endothecium and interlocking arrangement. $\times 679$.

FIG. 20. Uninucleate microspore. $\times 970$.

FIG. 21. Movement of nucleus near wall. $\times 970$.

FIG. 22. First division of microspore. $\times 970$.

FIG. 23. Two-celled pollen grain showing large vegetative cell and lenticular generative cell. $\times 970$.

FIG. 24. Mature pollen grain; note starch grains. $\times 970$.

generative cell and a large tube cell (Fig. 23). The generative cell divides to form the two male cells (Fig. 24). The mature pollen grain is ovoid and densely packed with starch grains. There is a thick exine with three germ pores. The intine is thin and membranous.

STRUCTURE OF THE OVARY.

The ovary is inferior, bicarpellary and syncarpous, with an indefinite number of anatropous unitegmatic, tenuinucellate ovules borne on axile placentae. The young ovary wall consists of ten to twelve layers of cells (Fig. 25). The outer cells are large and compact but the inner are smaller and more loosely arranged. Sparsely distributed unicellular hairs are found on the outer wall. They are stiff and pointed and their wall is beset with a number of minute projections (Fig. 26). In the mature fruit, all the cells of the ovary wall enlarge in size (Fig. 27). The portion of the ovary wall lying just below the base of the style undergoes certain changes. Here two or three layers of cells immediately next to the inner epidermis become prominently elongated and lignified (Fig. 28).

MEGASPORANGIUM AND FEMALE GAMETOPHYTE.

The single integument, which appears just after the differentiation of the hypodermal archesporial cell, is at first made up of three layers of cells (Fig. 35) but later becomes seven to eight-layered (Figs. 29, 30).

The hypodermal archesporial cell functions directly as the megaspore mother cell (Figs. 33, 35). Sometimes there are two archesporial cells (Fig. 34). Tetrad formation takes place normally (Figs. 36-39) and the chalazal megaspore functions. Sometimes the upper dyad cell shows a belated division (Fig. 40) or the division is oblique (Fig. 41). Occasionally the third megaspore shows signs of enlargement (Fig. 42). The nucleus of the functioning megaspore undergoes three successive

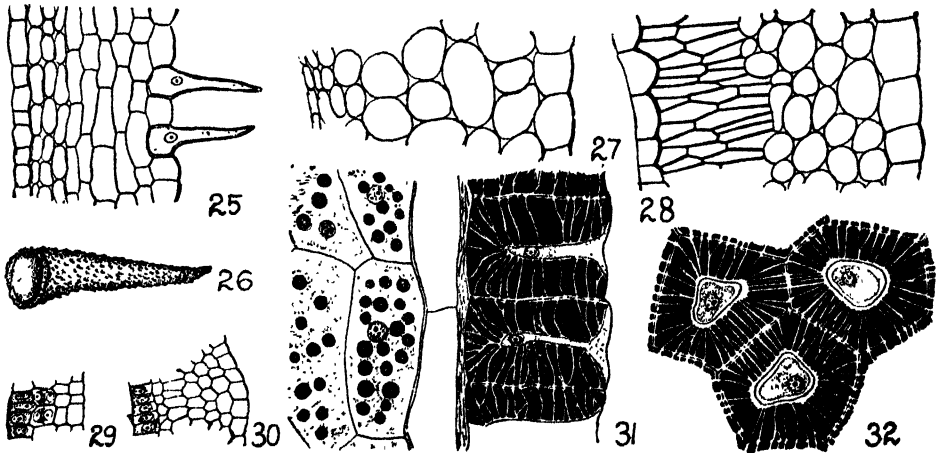


FIG. 25. Wall of young ovary. $\times 215$.

FIG. 26. Pointed unicellular hair enlarged. $\times 679$.

FIG. 27. Ovary wall at a later stage. $\times 129$.

FIG. 28. Upper portion of the ovary wall showing elongated layers of lignified cells next to the inner epidermis. $\times 129$.

FIGS. 29-30. Portions of the integument at different stages of development. $\times 129$ each.

FIG. 31. Portion of the seed-coat enlarged to show the thickened epidermis, disorganised middle layers and the endothecium; note also the starchy cells of the endosperm. $\times 679$.

FIG. 32. Epidermal cells of the seed-coat in surface view showing thickenings and the radially arranged canaliculae. $\times 679$.

divisions (Figs. 43-45) to produce an eight-nucleate embryo sac (Fig. 46) of the Polygonum type (Maheshwari, 1948).

During further development the cells of the nucellar epidermis are all destroyed, so that the mature embryo sac comes in direct contact with the innermost layer of the integument (Figs. 29, 30). This consists of rectangular cells with prominent nuclei and dense cytoplasm and forms the so-called endothelium (Fig. 47).

The mature embryo sac (Fig. 47) is elongated and tapering at both ends. The synergids are elongated and beaked, with the nuclei situated near the base. Sometimes they exhibit a filiform apparatus (Fig. 48). The pear-shaped egg is situated between the synergids. The two polar nuclei meet in the centre of the embryo sac (Fig. 46) and fuse to form the secondary nucleus. The antipodal cells (Figs. 46, 47) usually degenerate immediately after fertilisation.

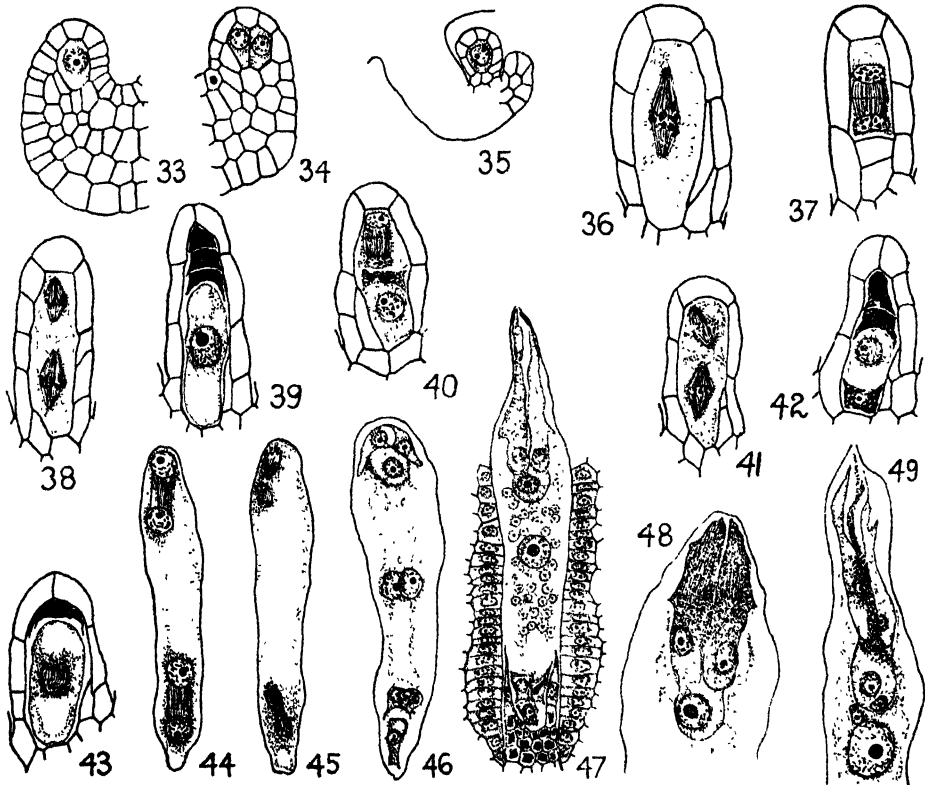


FIG. 33. L.S. of young nucellus showing primary archesporial cell. $\times 485$.

FIG. 34. Same showing two archesporial cells. $\times 485$.

FIG. 35. Ovule showing megaspore mother cell. $\times 291$.

FIGS. 36-37. Stages in the division of the megaspore mother cell. $\times 970$ and $\times 485$ respectively.

FIG. 38. Dyad cells dividing. $\times 679$.

FIG. 39. Tetrad of megaspores. $\times 679$.

FIG. 40. Belated division in upper dyad cell. $\times 679$.

FIG. 41. Dyad cells in division; note oblique division in upper cell. $\times 679$.

FIG. 42. Linear tetrad with third megaspore enlarging. $\times 679$.

FIGS. 43-45. First, second and third nuclear divisions in the formation of the embryo sac.

Fig. 43, $\times 679$; Figs. 44, 45, $\times 485$ each.

FIG. 46. Young embryo sac. $\times 485$.

FIG. 47. Mature embryo sac showing starch grains. $\times 485$.

FIG. 48. Egg apparatus enlarged to show filiform apparatus in synergids. $\times 679$.

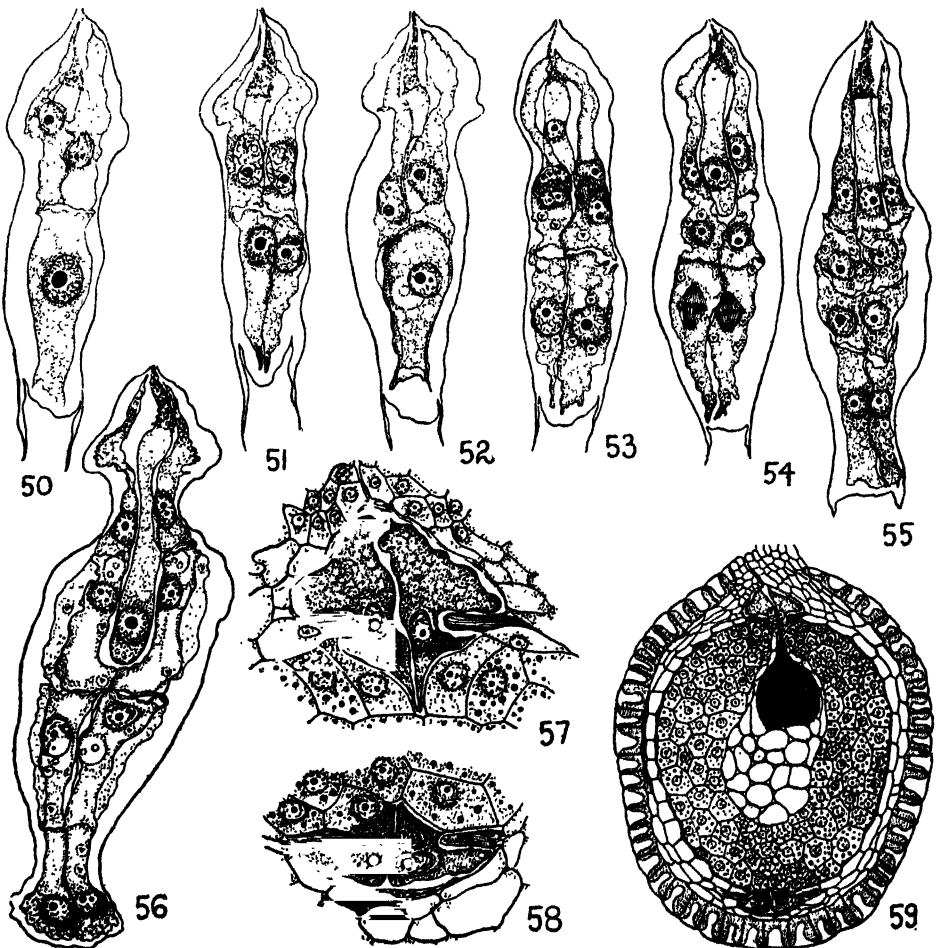
FIG. 49. A stage in double fertilisation. $\times 679$.

A large number of starch grains are present in the mature embryo sac (Fig. 47) and in the young endosperm cells (Figs. 53-56).

Fig. 49 is a stage in double fertilisation where the pollen tube has entered between the two synergids. Sometimes the pollen tube enters the embryo sac by destroying one of the synergids. In any case both synergids gradually shrivel and finally degenerate.

ENDOSPERM.

The primary endosperm nucleus, which is situated in the centre of the embryo sac, divides much earlier than the fertilised egg. A transverse wall is formed as a result of the first division, forming a primary micropylar and a primary chalazal chamber. A vertical wall is then laid down in the primary micropylar chamber (Fig. 50) and this is soon followed by a similar wall in the primary chalazal chamber



FIGS. 50-56. Stages in the development of the endosperm and the differentiation of the micropylar and chalazal haustoria. $\times 485$ each.

FIG. 57. Two-celled micropylar haustorium at advanced stage. $\times 485$.

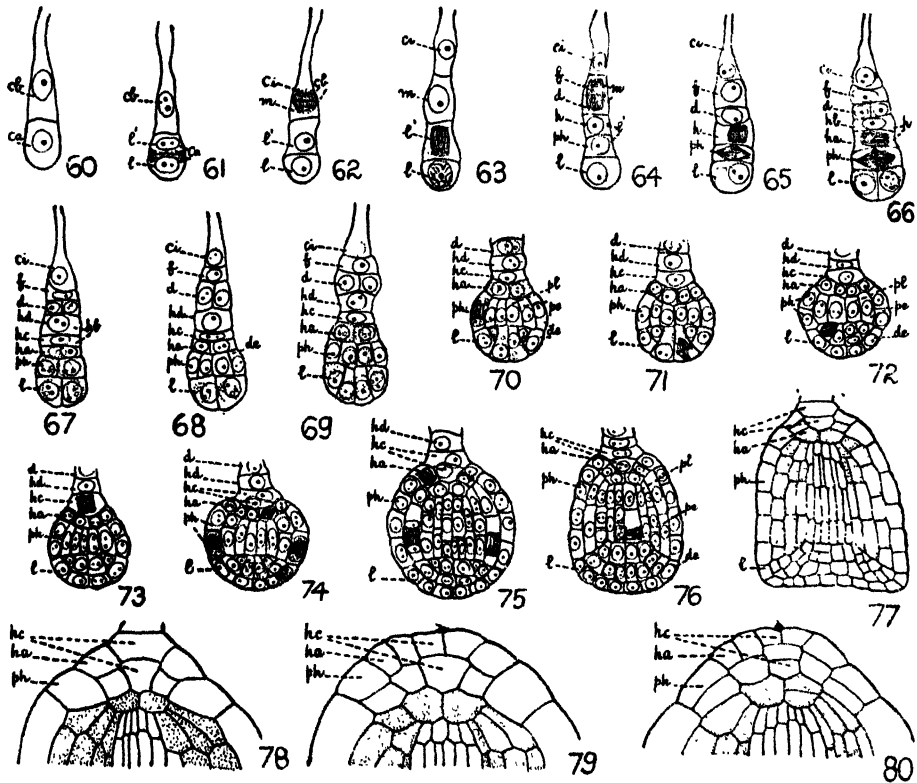
FIG. 58. Two-celled chalazal haustorium at advanced stage. $\times 485$.

FIG. 59. Longitudinal section of mature seed showing the embryo, the micropylar and chalazal haustoria, the starch-filled endosperm and the thickened epidermis. $\times 291$.

(Fig. 51). Sometimes, the vertical wall in the chalazal chamber is laid down at right angles to that in the micropylar chamber (Fig. 52). A four-celled endosperm is thus formed made up of two tiers of two cells each.

Next, transverse walls are laid down in both these tiers, first in the upper tier (Fig. 53) and then in the lower (Fig. 54). The result is, an eight-celled endosperm made up of four tiers of two cells each (Fig. 55). The two cells of the upper tier develop into the micropylar haustorium and the two cells of the lowest tier form the chalazal haustorium. The two middle tiers by further divisions develop into the endosperm proper (Fig. 56). The sequence of development thus follows the Scutellaria type of Schnarf (1931). A similar course of endosperm formation is met with in various species of *Lobelia* (Hewitt, 1939; Maheshwari, 1944; Kausik and Subramanyam, 1945b, 1946a; Subramanyam, 1949, 1951a).

The micropylar haustorium remains active for a long time (Fig. 57) and is made up of two uninucleate cells with pointed tips. They have a vacuolate cytoplasm, large nucleus and prominent lateral hump. This haustorium absorbs food from the micropylar cells of the integument. The chalazal haustorium (Fig. 58) is made up of two uninucleate cells which become extended and spread out towards the base.



FIGS. 60-77. Stages in development of embryo. $\times 291$ each.

FIGS. 78-80. Basal parts of three mature embryos at successive stages of development enlarged to show completion of periblem and organisation of the root tip and root cap. $\times 485$ each.

Lettering: *ca*—terminal cell of two celled embryo; *cb*—basal cell of two-celled embryo; *m* and *ci*—cells derived from basal cell *cb*; *d* and *f*—daughter cells of *m*; *l*—lower daughter cell of *ca*; *l'*—upper daughter cell of *ca*; *ph* and *h*—daughter cells of *l'*; *ha* and *hb*—daughter cells of *h*; *hc* and *hd*—daughter cells of *hb*; *de*—dermatogen; *pe*—periblem; and *pl*—plerome.

It ceases its activities earlier than the micropylar haustorium. The endosperm cells lying between the haustoria are densely packed with starch grains except in the region immediately surrounding the developing embryo (Fig. 59).

EMBRYO.

The division of the fertilised egg takes place only after the initial stages of endosperm formation. It divides transversely forming a terminal cell *ca* and a basal cell *cb* (Fig. 60). Of these, *ca* divides first by a transverse wall (Fig. 61) followed by a similar division in *cb* (Fig. 62) resulting in the formation of a filamentous pro-embryo of four cells, *l*, *l'*, *m* and *ci*.

The cell *l'* divides transversely producing *ph* and *h* (Figs. 63, 64) and *h* undergoes a similar division to form *ha* and *hb* (Figs. 65, 66). Synchronously the lowest cell *l* divides vertically (Fig. 64) and similar vertical divisions take place in *ph* (Fig. 65) and *ha* (Fig. 66). Next *l* and *ph* undergo another vertical division at right angles to the first thus producing two tiers of four cells each (Figs. 66, 67).

While these divisions are taking place in the lower tiers, *m* divides transversely to form *d* and *f* (Figs. 64, 65). Meanwhile *hb* undergoes a transverse division to form *hc* and *hd* (Fig. 67). Cells *hd*, *d*, *f* and *ci* now constitute the filamentous suspensor (Figs. 67-69). Of these, *d* divides vertically to form two juxtaposed cells (Figs. 66-71). The embryo proper is formed by the cells *l*, *ph*, *ha* and *hc*.

Anticlinal walls are laid down first in tier *ph* (Fig. 68) and then in tier *l* (Fig. 69); this is followed by the laying down of periclinal walls in *l* (Figs. 70-73) to cut off the dermatogen. The inner cells of tier *ph* divide longitudinally separating the future periblem from the plerome (Fig. 70). Both longitudinal and transverse divisions occur in the further development of the plerome and periblem (Figs. 71-78).

While these changes are going on in the two lower tiers of cells, *ha* undergoes further longitudinal divisions to form an arc-shaped group of four cells (Figs. 71-73). Later the number increases to six (Figs. 74-78). The two innermost cells of this group take part in the completion of the periblem (Figs. 77-80) and the remaining cells contribute to the dermatogen and root cap.

The cell *hc* divides only in comparatively late stages. Two cells are formed (Fig. 73) of which the lower divides transversely and the upper vertically and all the derivatives take part in the formation of the root cap (Figs. 79, 80). A further contribution is made to the root cap by the uppermost cells of the tier *ha* which divide anticleinally as well as extra cells produced by the periclinal divisions of the upper cells of the dermatogen belonging to tier *ph* (Figs. 79, 80).

In the maturing embryo (Fig. 77) the respective contributions of the primary tiers may be summarised as follows: *l* gives rise to the cotyledons and the stem tip; *ph* to the hypocotyl which has a central row of long and narrow plerome cells, a middle zone of the more elongated periblem cells (the region shown dotted in Figs. 77-80) and the outermost layer or dermatogen; *ha* contributes to the periblem and a part of the root cap; and *hc* to the remaining part of the root cap. An essentially similar course of development is seen in other members of this family (Cr  t  , 1938; Hewitt, 1939; Kausik, 1935, 1938; Kausik and Subramanyam, 1945a, b; 1947b; Subramanyam, 1949).

DEGENERATION.

Occasionally degenerations were noticed both in the anther and ovary. Fig. 11 is a transverse section of a portion of the anther lobe where all the pollen mother cells have degenerated. The vacuolate tapetal cells show granular contents and have enlarged prominently. In the same flower, the ovules had developed in the usual manner. In certain other flowers, however, pollen was formed normally, but no ovules were seen in the ovary (Fig. 12).

SEED COAT.

In the mature seed, only the epidermal cells and the endothelium persist (Fig. 31). The middle layers of the integument are completely crushed. The cells of the endothelium remain thin-walled and empty. The epidermal cells develop characteristic thickenings. The lateral and inner walls of these cells are strongly thickened due to deposition of lignin, so that the cavity of each cell is extremely reduced. Each cell is in communication with its neighbouring cells by means of canals which are long, narrow and sometimes branched (Fig. 32).

DISCUSSION.

The floral structure of *Isotoma fluviatilis* presents certain interesting features. Around the base of the style there is a prominent nectary whose epidermal cells are modified into secretory hairs. The presence of stiff hairs at the apex of anthers, the stylar brush, the formation of an anther tube by the almost syngenesious anthers and the well-developed nectary at the base of the style are all special adaptations for cross pollination.

Sparsely distributed unicellular hairs are present on the outer epidermis of the ovary wall. The inner two or three layers of apical part of the ovary wall, next to the inner epidermis, become prominently elongated and strongly lignified.

The haploid number of chromosomes is seven.

Certain variations seen during megaspore tetrad formation like belated division in the upper dyad cell or its oblique division are also met with in other members of this family (Subramanyam, 1949) and members of Campanulaceae (Kausik and Subramanyam, 1947a; Subramanyam, 1948) and Stylidiaceae (Rosén, 1935; Subramanyam, 1950, b, c; 1951b). The tendency for any one of the megaspores of the tetrad to show signs of enlargement is also recorded for other members of this family (Kausik, 1938; Kausik and Subramanyam, 1945b) and Campanulaceae (Subramanyam, 1948).

The development of the male and female gametophytes is similar to that reported in other members of the Lobeliaceae. Starch grains are present in the mature pollen grain and embryo sac as in certain members of the closely allied families Campanulaceae (Kausik and Subramanyam, 1947a; Subramanyam, 1948) and Stylidiaceae (Burns, 1900; Subramanyam, 1951b). The filiform apparatus, seen in the synergids, also occurs in *Lobelia cardinalis* (Cooper, 1942) and *L. pyramidalis* (Subramanyam, 1949).

Development of endosperm follows the Scutellaria type (Schnarf, 1931) as in *Lobelia* (Hewitt, 1939; Maheshwari, 1944; Kausik and Subramanyam, 1945b, 1946a; Subramanyam, 1949, 1951a) and certain members of Stylidiaceae (Rosén, 1935; Subramanyam, 1950b, c; 1951b). Rosén (1949) reports the Codonopsis type in *Isotoma axillaris* but this is only a further elaboration of the Scutellaria type of endosperm (see Subramanyam, 1950a). It is interesting to note that in *Isotoma longiflora* (Kausik and Subramanyam, 1945a) two types of endosperm development, viz., the Phyteuma type and Isotoma type, are met with in one and the same plant. In the Campanulaceae the Codonopsis and Phyteuma types predominate (Rosén, 1932, 1949).

In the genus *Isotoma* the Scutellaria type occurs in *I. fluviatilis*, Codonopsis type in *I. axillaris* (Rosén, 1949) and Phyteuma and Isotoma types in *I. longiflora* (Kausik and Subramanyam, 1945a). Thus *Isotoma* shows similarities not only with the genus *Lobelia* but also with members of the Campanulaceae.

The development of the embryo follows a fairly uniform plan in the Lobeliaceae (Kausik, 1935, 1938; Crété, 1938; Hewitt, 1939; Kausik and Subramanyam, 1945a, b; 1947b; Subramanyam, 1949) as well as the Campanulaceae (Souèges, 1936, 1938; Kausik and Subramanyam, 1947a; Subramanyam, 1948; Crété, 1948).

It thus becomes evident that the families Campanulaceae, Lobeliaceae and Stylidiaceae are closely related to one another not only in their floral characters but also with respect to their embryology.

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SUMMARY.

A nectary is present around the base of the style and the epidermal cells of the nectary are modified into secretory hairs.

The wall of the anther consists of three layers external to the tapetum. The tapetal cells are binucleate and are of the glandular type. The endothecium is fibrillar. The haploid number of chromosomes is 7. The mature pollen grain is three-celled and encloses starch grains.

The inferior ovary is bilocular with indefinite number of anatropous tenuinucellate ovules borne on the axile placenta. Sparsely distributed unicellular hairs are present on the outer epidermis of the ovary wall. The inner two or three layers of the apical part of the ovary wall, next to the inner epidermis, become elongated and lignified.

There is usually a single archesporial cell and this directly functions as the megaspore mother cell. Sometimes two archesporial cells are present. Megasporogenesis proceeds normally and the development of the embryo sac is of the Polygonum type. Starch grains are present in the mature embryo sac. The synergids are beaked and sometimes exhibit a filiform apparatus. The antipodals are organised as cells. Double fertilisation has been observed.

Endosperm development is cellular and follows the Scutellaria type. The micropylar haustorium is made up of two uninucleate cells and is more aggressive than the chalazal haustorium.

Development of the embryo has been studied in detail.

The mature seed contains a mass of endosperm filled with starch grains. The epidermal layer of the seed coat develops characteristic thickenings.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART VI.

STUDIES IN THE DISTRIBUTION AND CONCENTRATION OF ALKALINE PHOSPHATASE IN THE OVIDUCT OF NORMAL AND OF SEX HORMONE-TREATED PIGEONS.*

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INTRODUCTION.

The presence of alkaline phosphatase has been demonstrated cytochemically in the female genital tract of several species of mammals and in the pigeon. The literature pertaining to phosphatase activity in the female genitalia of mammals have been summarised and discussed broadly by Kar (1950). In juvenile pigeons, about 4 months old, there are only traces of the enzyme in some component tissues of the oviduct except, however, in the young tubular glands of the mucosa where appreciable amounts of the phosphatase are present. Progesterone treatment causes a pronounced hypoplasia of the oviduct and concomitantly, the enzyme disappears totally from the various oviducal elements. Desoxycorticosterone acetate administration is associated with a marked enlargement of the oviduct but very little augmentation of phosphatase activity is seen in this organ (Kar, 1950).

The present report has been concerned with an attempt to study the effect of estradiol dipropionate and testosterone propionate on the distribution and concentration of alkaline phosphatase in the oviduct of juvenile pigeons.

EXPERIMENTAL.

Female pigeons 90 days old were used in this study. A total of 15 birds were taken of which 5 were injected with estrogen, 5 with androgen, and the remaining 5 were left uninjected to serve as controls. The birds were housed in cages and maintained under uniform husbandry conditions throughout the duration of the experimental period.

Testosterone propionate in sesame oil was administered intramuscularly. The daily injections (2.5 mgm.) were made into the breast muscles and continued for a period of 10 days. An equal amount of estradiol dipropionate (2.5 mgm. or 25,000 dipropionate units daily) was injected in a similar manner and over the same period of time. The site of injections were altered from day to day on the right and left sides of the breast.

* A preliminary report of this investigation was presented before the Medical and Veterinary Section of the 37th Indian Science Congress, Poona Session, 1950 (See *Proc. Ind. Sci. Congr. Abs.*, 1950, pp. 803-804).

All the birds were autopsied on the day following the final injection. Pieces of the oviduct from the magnum region were fixed immediately in cold (5° to $12^{\circ}\text{C}.$) 80 per cent ethyl alcohol and in Bouin's fluid. After dehydration and imbedding in paraffin, serial sections were cut 6 microns in thickness. The tissue fixed in Bouin's fluid was stained with Mallory's trichrome stain. The sections of the oviduct fixed in ethyl alcohol were incubated in sodium glycerophosphate substrate (pH 9.5) according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. The sites of phosphatase activity in the tissue sections are marked by the deposition of cobalt sulfide in fine black granules. In order to avoid obscuring these deposits no counterstains were used. The sections were dehydrated and mounted in the usual manner.

RESULTS.

Control: Test for alkaline phosphatase is entirely negative in the component tissues of the oviduct. However, minute traces of the enzyme are seen in the epithelium bordering the low mucosal folds (Pl. VII, fig. 1). The muscularis, connective tissue stroma, and the endothelium of the blood vessels are devoid of phosphatase activity.

Estrogen treatment: Estrogen treatment causes a spectacular mobilisation of alkaline phosphatase in the oviduct. The greatly thickened muscularis shows moderate amounts of the enzyme. The nucleus of the stromal connective tissue cells exhibits greater phosphatase activity than the cytoplasm and in the blood vessels of this region the enzyme is localised in the endothelium. The stratified epithelium bordering the villus-like mucosal folds show strong positive reactions for the phosphatase. The enzyme appears to be uniformly distributed in the nucleus and in the cytoplasm of the stratified epithelial cells. The maximal concentration of the phosphatase is seen in the well-developed tubular glands of the mucosa (Pl. VII, fig. 2). The glandular cells show a remarkable mobilisation of alkaline phosphatase in the nucleus as well as in the cytoplasm.

Androgen treatment: Androgen treatment is also associated with an increase in phosphatase activity in the oviduct. However, the degree of this augmentation in enzyme activity appears to be almost negligible when compared with that in the oviduct of estrogen-treated specimens. The muscularis shows very little phosphatase activity and the amount of the enzyme in the stroma is variable. The stromal tissue that extends throughout the axial portion of the enlarged mucosal folds shows only nuclear phosphatase while in the submucosal connective tissue the enzyme is present in the cytoplasm as well. The endothelium of the stromal blood vessels shows slight reactions for the enzyme. There is no glandular development and consequently the phosphatase activity in the mucosa is practically absent. The columnar cells of the mucosal epithelium, however, show moderate amounts of the enzyme (Pl. VII, fig. 3).

DISCUSSION.

The present studies have indicated clearly that there is very little or no phosphatase activity in the immature oviduct of juvenile pigeons. Treatment with sex hormones is undoubtedly associated with an increase in the amount of oviducal phosphatase. However, the degree of this augmentation is much more pronounced in the oviduct of birds receiving estrogen than in that of the androgen-treated specimens. The results obtained after estrogen treatment, therefore, are not out of keeping with the previous work on mammals which demonstrated that estrogen mobilised alkaline phosphatase in the uterus of the mouse (Atkinson and Elftman, 1946 and 1947), and in the entire genital tract of the female rat (Talmage, 1949).

A point of considerable interest is the almost negligible augmentation of phosphatase activity in the oviduct of androgen treated birds. It has been reported

previously (Kar, 1950) that desoxycorticosterone acetate is similarly ineffective in increasing the amount of oviducal phosphatase, although the duct shows marked development of the component tissues but not of the tubular glands, the main functional units of this organ. The effect of these two hormones on the phosphatase activity in the pigeon's oviduct, therefore, appears to be more or less similar.

A question may now be raised concerning the possible function of the phosphatase in the avian oviduct. In this connection it should be noted that cytochemical studies alone serve only to localise the enzyme and to give a rough estimate of its concentration. However, by reckoning the state of phosphatase activity in the oviduct against the physiological processes known to occur in this organ, the possible rôle of this enzyme may be suggested.

Estrogen plays a very vital rôle in the physiology of the avian oviduct. It stimulates glandular development in order to bring the organ to a functional state (for references see Kar, 1947 *a* and *b*; 1949). In the material under report also, the estrogen acted in a likewise manner and caused pronounced glandular development in the oviduct (see Pl. VII, fig. 2). Further, on the basis of the data recorded here, we feel justified to assume that in the estrogen-treated birds a physiological relationship exists between the development of the tubular glands and the concomitant increase in phosphatase activity in the oviduct. In other words, it appears probable that this functional stimulation of the duct is brought about by the hormone through the augmented activity of the enzyme. The results obtained after androgen treatment provide an evidence in support of this concept. The testoid undoubtedly failed to induce glandular development, and this hormonal ineffectiveness seems to be the outcome of only a negligible increase in phosphatase activity in the oviduct. The situation, as we have already pointed out, is comparable to a similar one that is encountered in the oviduct of this species after DCA treatment (Kar, 1950). These results, therefore, when added together, lead one to the unavoidable conclusion that the phosphatase plays an important rôle in the functional development of this typical avian organ.

SUMMARY.

The distribution of alkaline phosphatase has been studied cytochemically in the oviduct of normal and of sex hormone-treated pigeons. In the oviduct of normal juvenile pigeons there is very little or no phosphatase activity which, however, is markedly increased in the duct of the estrogen recipients. Androgen treatment is much less effective in augmenting the oviducal enzyme activity. The possible physiological rôle of alkaline phosphatase in the avian oviduct is discussed.

ACKNOWLEDGMENTS.

The author wishes to express his indebtedness to Dr. B. Mukerji, Director, Central Drugs and Pharmacognosy Laboratories, for constant help and encouragement. Grateful acknowledgment is made to Dr. K. H. Gruschwitz of Ciba Pharma, Ltd., Calcutta, for generous contribution of testosterone propionate (Perandren) and estradiol dipropionate (Ovocyclin P) used in this study. Sincere thanks are also due to the author's erstwhile Chief, Professor F. B. Hutt of Cornell University, Ithaca, N.Y., U.S.A., for supply of Sodium Barbitol (Merck). Co-operation of Sri P. C. Pathak in taking the photomicrographs which illustrate this article is greatly appreciated.

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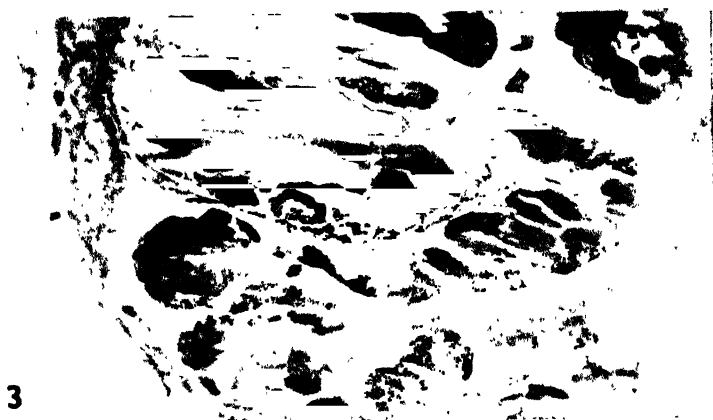
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PLATE VII.

EXPLANATION OF FIGURES.

- Fig. 1. Photomicrograph of a portion of the section through the oviduct of a control pigeon ($\times 200$). Alkaline phosphatase is present only in traces in the luminal epithelium of some mucosal folds.
- „ 2. Photomicrograph of a portion of the section through the oviduct of an estrogen-treated pigeon ($\times 200$). Note the heavy mobilisation of alkaline phosphatase.
- „ 3. Photomicrograph of a portion of the section through the oviduct of an androgen-treated pigeon ($\times 200$). Phosphatase reaction is much less intense. Compare with fig. 2.



DISTRIBUTION OF CLARIID FISHES, AND ITS SIGNIFICANCE IN ZOOGEOGRAPHICAL STUDIES.

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(Communicated by Dr. S. L. Hora, F.N.I.)

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INTRODUCTION.

The discovery of a new blind Clariid fish from Travancore (Menon, in press)¹ and the occurrence of a similar blind Clariid fish *Uegitglanis* Gianferrai in the Italian Somaliland have raised points of great zoogeographical interest. In elucidating these points, the distribution of the Clariidae, both in time and space, had to be carefully investigated and this led the writer to some important considerations which form the subject matter of this article. It may be recalled that the Clariidae are a highly specialized family of air-breathing fishes, showing relationships to the Schilbeidae. Besides important osteological characters, the gill cavity of the Clariidae is provided with a diverticulum containing a dendritic accessory branchial organ attached to the second and fourth branchial arches.

¹ The description of the new genus *Horaglanis* and of the species *H. krishnai* have been submitted for publication in the *Records of the Indian Museum*. As there is usually considerable delay in the publication of this journal, a brief description of the new fish is given below to satisfy International Rules of Zoological Nomenclature.

Horaglanis, gen. nov.—Pectoral vestigial; eyes absent; gill membranes united with isthmus; air bladder free; dendritic branchial apparatus vestigial.

Locality.—Well at Kottayam, Travancore, South India.

Type-species.—*Horaglanis krishnai*, gen. et sp. nov.

Horaglanis krishnai, gen. et sp. nov.—D. 23, P.O. V. 6, A. 17, C. 22. Length of head 5.6 times and height of body 7.7 times in standard length. Other main characters as of the genus.

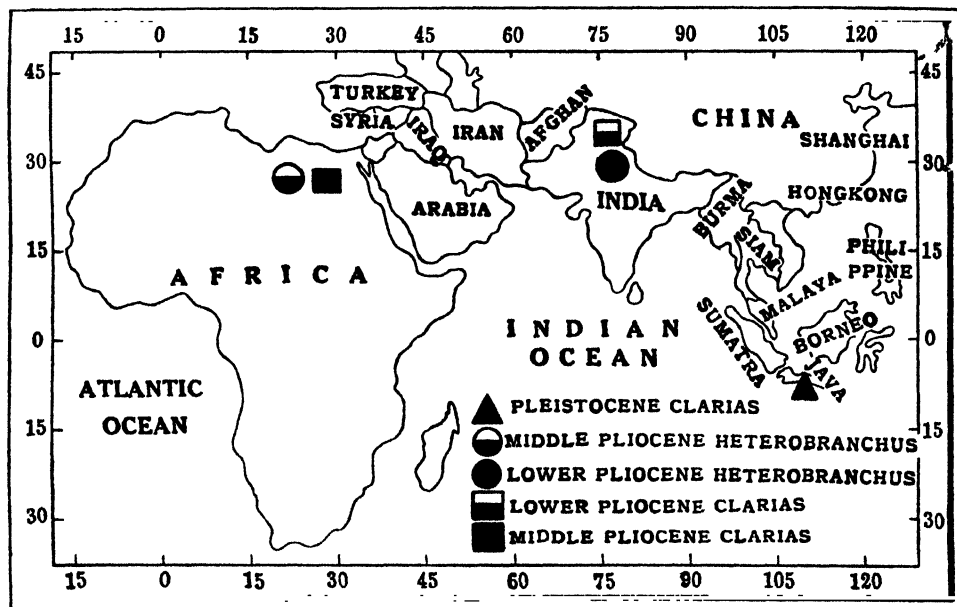
Holotype.—F 313/2, Zoological Survey of India, Calcutta.

DISTRIBUTION IN TIME.

Lydekker (1886, pp. 247-249) found fossils of *Clarias* Gronovius and *Heterobranchus*¹ Geoffroy in the Lower Pliocene deposits of the Siwalik Hills. Taking into consideration the present-day discontinuous distribution of the latter genus, he observed:

'The occurrence of a species of *Heterobranchus* in the pliocene of India is extremely interesting as affording another instance of the probable migration of existing African genera from an Oriental centre of distribution.'

The next fossil record of the Clariidae is from the Middle Pliocene of the Natron Valley in Egypt (*vide* David, 1936, p. 134). Whether this record refers to *Clarias* or *Heterobranchus* is not clear from the nature of the specimen. Koumans (1944) has recently described some fossil fish remains from Java, among which he found bones of *Clarias batrachus* and *Clarias* prox. *leiocanthus*. These remains are mainly from the Pleistocene deposits. David also refers to a record of *Clarias* by Henning from the *Pithecanthropus stratum* (Pleistocene) of Java.



TEXT-FIG. 1. Map of S. Asia and Africa showing the distribution of the fossil Clariidae.

¹ The genus *Heterobranchus* is chiefly distinguished from *Clarias* by the structure of the dorsal fin (rayed throughout in *Clarias* versus divided into two parts in *Heterobranchus*) and by the better development of the suproccipital process in *Heterobranchus*. Herre and Myers (*Bull. Raffles Mus. Singapore*, No. 13, p. 68, 1937) have separated the only known Asiatic species of *Heterobranchus tapeinopterus* from the African species by instituting a new genus *Encheloclarias* for it. Unfortunately, they do not indicate any precise characters on which the two genera can be separated, but it would appear that the present-day discontinuous distribution of *Heterobranchus* may have influenced them to adopt this course. They state:

'It seems probable that *tapeinopterus* is not directly related to the African species of *Heterobranchus*, in spite of the fact that comparison of our single specimen with African forms shows striking similarity in many respects.'

The arguments on which *Encheloclarias* is generically separated from *Heterobranchus* seem to be feeble but, in the absence of any material of either, I am not in a position to discuss the matter further. Both taxonomic and zoogeographic requirements will be satisfied if *Encheloclarias* is for the time being treated as a sub-genus of *Heterobranchus* and this course will be adopted in this paper.

The abovementioned fossil records of the Clariidae lead one to the following conclusions:—

1. The family probably originated in the Early Pliocene period in the Siwalik areas.
2. The dispersal of these fishes towards the west to Africa and east to China was facilitated by the Siwalik climatological conditions that prevailed over very large areas during the Pliocene period.
3. The southward extension of the range of the family, both in Africa and Asia, occurred during the Pleistocene period.

After considering the present-day distribution of the family, the above conclusions will be assessed in locating the centre of origin of the family. It will be necessary to give a brief account of the Pliocene ecological conditions that seem to have favoured the evolution of the family.

PLIOCENE CLIMATES

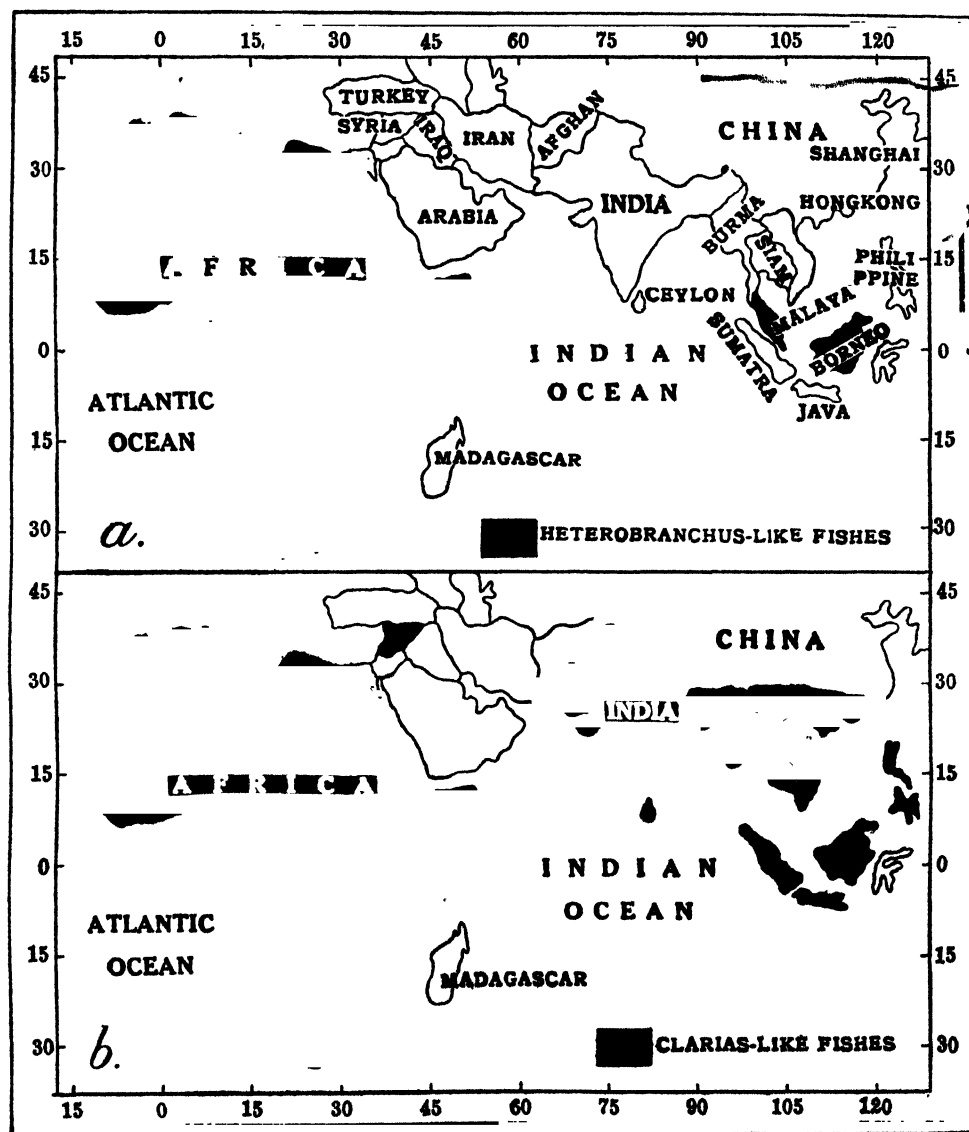
There is always an ecological specificity in the distribution of animals and generally it is permissible to refer to the earlier geological and climatic conditions in terms of the present-day ecological features of a species, genus or family. The Clariidae in Asia live abundantly in extensive marshy areas where during the dry periods waters become foul and deficient in oxygen or dry up altogether. In such habitats the breathing of atmospheric air direct becomes a necessity. Besides the Clariidae, several other kinds of fishes, such as *Heteropneustes*, *Anabas*, *Ophicephalus*, *Amphipnous*, etc. have acquired the habit of aerial respiration. Lydekker (1886, p. 246) also recorded *Ophicephalus* from the Siwaliks. The fossil records of rhinoceros, antelope, elephant, tiger, hyaena, etc., in the Pliocene deposits of Siwaliks (Lydekker, 1883) indicate that the ecological conditions prevailing then over the Siwaliks must have been similar to those of the Sunderbans area today in the Gangetic Delta.

The Siwalik climatological conditions evidently seem to have extended over a very wide area as representatives of the Siwalik fauna have been recorded as far east as China (Lydekker, 1883, p. 81). On geological evidence, Wadia (1939) has indicated the extension of the Siwalik strata as far as Baluchistan in the west. The distribution of the Clariidae shows that similar climatic conditions must have prevailed beyond Baluchistan to the west. From these data, it can be surmised that, during the Pliocene, wet, tropical, marshy conditions prevailed along the whole of northern India, extending to China on the east and beyond Baluchistan towards the west. The disappearance of the marsh-loving animals, including the Clariidae, from countries between India and Africa would, perhaps, be a consequence of the retreat of the Siwalik conditions from there and the gradual drying up of the area. This conclusion is very much strengthened by the fact that the rhinoceros, which at present is confined to the forests east of the Ganges, had a much wider distribution in the north-western parts of India till recent times (Everest, 1834). The Clariidae also responded to this desiccation process and are only rarely found beyond Delhi but are most abundant in the marshy areas of Lower Bengal (Hora, 1939), Assam, Bihar and Orissa.

PRESENT-DAY DISTRIBUTION AND SPECIATION AMONG THE CLARIIDAE.

Distribution of the family.—Taking the family as a whole, we find that it is at present found in the East-Indian Archipelago, South-east Asia, Syria and Africa. Its absence from Sind, Baluchistan, Persia and Arabia gives it a discontinuous distribution but, as remarked above, when these areas had a wet climate not very long ago the distribution of the family was probably continuous. The retreat of the favourable Siwalik conditions from these areas appear to have been the main reason for their absence from these countries now.

Distribution of Heterobranchus and allied forms.—There are three genera, *Heterobranchus* (Africa,) *Dinotopterus* (Africa) *Encheloclarias* (Borneo and Malaya), which are to be considered under this section. I have already shown (*vide supra*, p. 292 foot-note) that *Encheloclarias* can at best be considered a subgenus of *Heterobranchus*. *Dinotopterus*, in which the sides of the head are naked and the small adipose fin is not supported by bony rays, is sufficiently distinct from *Heterobranchus* and shows parallel development of structures to that met with among the *Clarias*-group of genera. There is no doubt that the evolution of *Dinotopterus* was induced by the ecological conditions prevailing in Lake Tanganyika. The occurrence of *Hetero-*



TEXT-FIG. 2. a. Map of S. Asia and Africa showing the distribution of the *Heterobranchus*-like fishes.

b. Map of S. Asia and Africa showing the distribution of the *Clarias*-like fishes.

branchiis in the Pliocene Siwaliks helps us to bridge the wide gulf between the living representatives of this group of fishes. Their discontinuous distribution undoubtedly shows their antiquity. It would also appear that this group of Clariid fishes is not so hardy as the *Clarias*-group and could not probably exist over a wide area greatly influenced by the orogenic movements of the Himalayas during the Pliocene and Pleistocene periods.

Distribution of Clarias and closely allied genera.—*Clarias* is the most widely distributed genus of the family and its range is co-extensive with that of the family. Its fossil records from the Early Pliocene Siwaliks in India, Middle Pliocene formations of Egypt and Pleistocene beds of Java also show that the genus had a very wide distribution in earlier times. On the continent of Asia, it is represented by twelve species¹, some of which have a very restricted distribution while *Clarias batrachus* (Finn.) is found everywhere. With the exception of *Horaglanis*, to which reference will be made subsequently, *Clarias* has not given rise to any good genus in Asia², whereas in Africa, finding many divergent conditions of life, it has proliferated into several distinctive genera.

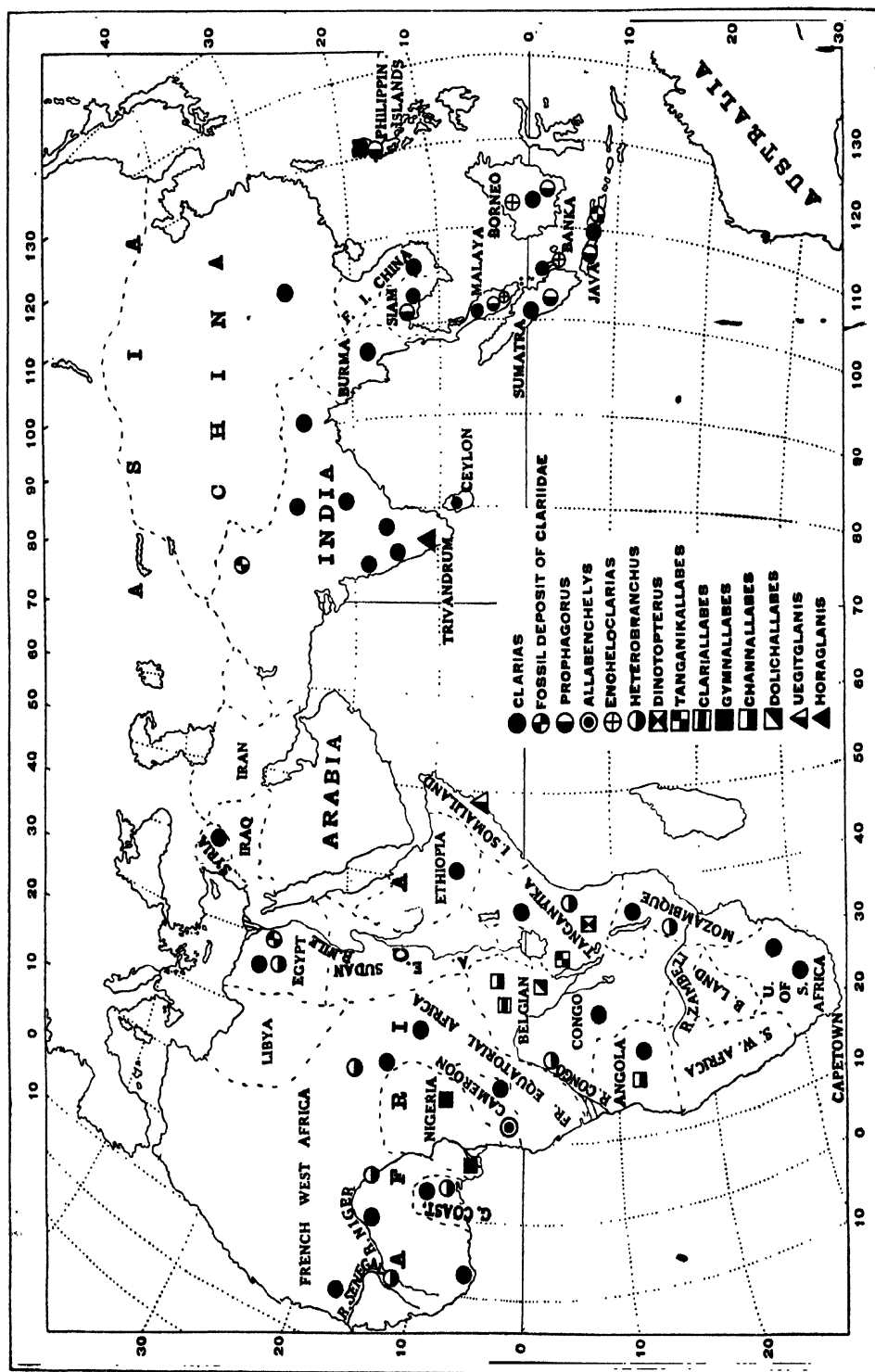
Of these, the genera with the *Clarias*-like form are *Allabenchelys* Brevier (South Cameroon) *Clariallabes* Blgr. (Lower Congo) and *Tanganikallabes* Poll (Tanganyika). As in *Dinotropterus*, of the *Heterobranchus*-group, the sides of the head are naked in all the three genera. Whereas in *Allabenchelys* the eyes have a free border, in the other two genera the eyes are without free borders. Those without free eye border are distinguished by the character of the caudal fin, which is confluent with the dorsal and anal in *Clariallabes* and is free in *Tanganikallabes*. All these generic differences seem to have been induced by taking to a burrowing habit of life when protective shields from the sides of the head could be dispensed with and eyes could also be allowed to degenerate. Probably similar ecological conditions lack in Asia where *clarias* has remained as such and has not budded off any genera.

Distribution of the Eel-like Clariid fishes.—There are three genera of eel-like Clariid fishes, namely *Gymnallabes* Günther (Lower Niger and old Calabar), *Channallabes* Günther (Congo and Angola) and *Dolichallabes* Poll (Belgian Congo). These genera are the product of evolution induced by the accentuation of the burrowing habit of life. The protective head-shields are still further reduced and the caudal more intimately confluent with the dorsal and anal fins. The eyes are also further reduced. As a direct result of the burrowing habit of life, the pectoral and pelvic fins are reduced or totally absent. The characters by which these genera are separated from one another are the direct result of ecological conditions, like the which are

¹ The distribution of the Asiatic species of *Clarias* is as follows:—

1. *C. batrachus*, widely distributed;
2. *C. fuscus*, S. China;
3. *C. leiocanthus*, Malay Archipelago and Siam;
4. *C. macrocephalus*, Siam, F.I. China and Philippines;
5. *C. melanoderma*, S. China, Siam, Malay Archipelago and Philippines;
6. *C. teysmanni*, " " " " "
7. *C. syriacus*, Syria;
8. *C. dayi*, Wynad Hills, W. Ghats, India;
9. *C. dussumieri*, W. Ghats, India;
10. *C. brachysoma*, Ceylon;
11. *C.* (= *Prophagorus*) *cataractus*, Siam;
12. *C.* (= *Prophagorus*) *neiuhofii*, Siam, Malay Archipelago and Philippines.

² The validity of the genus *Prophagorus* Smith (1945, p. 352) erected to accommodate Clariid fishes with dorsal and anal fins confluent with caudal is questionable, the first description of the genus (*Progorus* McClelland, 1845) having been based on a mutilated specimen of *Clarias batrachus*. Similar specimens had been described by Hamilton (*vide* Hora, 1933, p. 133), Bleeker (*vide* Günther, 1864, p. 19) and Hora (1936, pp. 347-48). Deraniyagala (*vide* Hora) remarked regarding *Clarias brachysoma* of Ceylon that 'specimens are frequently found with regenerate caudal, which is then confluent with the dorsal and anal and lacks the hypural bones'. In view of these considerations, I do not regard *Prophagorus* as a valid genus.



TEXT-FIG. 3. Map of S. Asia and Africa showing the distribution of the genera of Clariidae.

Here the distribution of the genera as accepted at present is shown, but in the paper the author has shown that the Asiatic *Enche-
loclarias* can at best be considered only as a sub-genus of the African *Heterobranchius*, and *Prophagorus* is the same as *Clarias*.

probably absent in South-East Asia. It should also be noticed that these specialized genera have a limited local distribution.

Distribution of Blind Clariid fishes.—A typical *Clarias* without eyes has been described by Trewavas (1936, pp. 70-71) from caves in South-West Africa. Here the modification is the consequence of one environmental factor, namely perpetual darkness while other factors seem to have been normal. There are two blind genera of the family which live in wells or the underground waters connected with them and have undergone very remarkable changes. *Uegitglanis* Gianferrai is known from Africa (Italian Somaliland) and *Horaglanis* Menon from India (Travancore). They have undoubtedly evolved independently under subterranean conditions of life in these widely separated areas.

Speciation among the Clariidae.—The similarities between the Indian and African Clariidae are due to common ancestry, whereas differences are due to ecological factors that influenced evolution in the two regions after the isolation of the original stock. The greater variety of conditions prevailing in Africa has no doubt been the inducing factor in the evolution of genera and species. Starting with the *Heterobranchus* and *Clarias* stocks in about the Middle Pliocene, several genera, evolved more or less in a linear series, have been produced in Africa showing thereby the great plasticity of these fishes to changed environmental conditions in Africa and to the rigidity of their structure under ancestral conditions in South-East Asia.

ROUTE OF DISPERSAL OF THE CLARIIDAE.

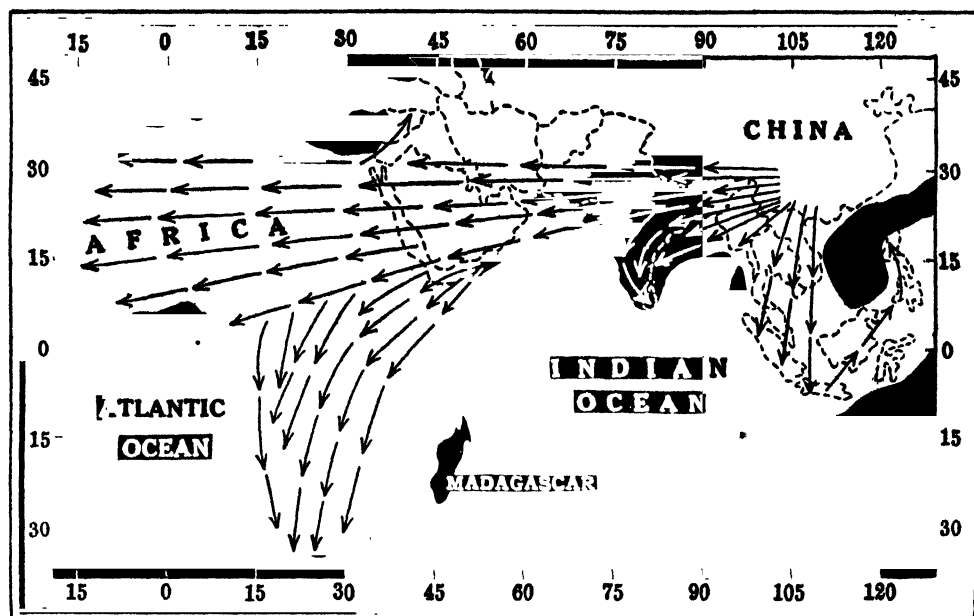
All students of ichthyology are generally agreed that the Clariidae originated in the Oriental Region and thence spread westwards to Africa. Reference has already been made to Lydekker's views (*vide supra*, p. 292). David (1936, p. 135) thought the dispersal to Africa was over a land route that included Madagascar. If the family originated in the early Pliocene, such a southward route is improbable because the so-called continent of Lemuria probably disappeared as early as the Eocene. Further, no Clariidae have so far been recorded from Madagascar. On the other hand there is considerable amount of evidence that favours a northern route. We have shown above that the Siwalik climatological conditions were wide-spread both to the east and west of India and must have been an important factor in the dispersal of the Clariidae. Recent investigations concerning the geological history of the floor of the Arabian Sea have revealed that

'the floor of the north-western part of the Indian Ocean, as we know it today assumed its present form as a result of compression in Tertiary times, probably contemporaneously with the upheaval of the Alpine-Himalayan Mountain system and the arcs of the Malayan Archipelago and the formation of the Rift Valley. Consequently in Pliocene or Post-Pliocene times the area of land that once filled the triangle now bounded by the northern part of the East African coast and its continuation, the south-east coast of Arabia, the Baluchistan coast, and the west coast of India, became separated off by a series of faults and was submerged to its present depth.' (Wiseman and Sewell, 1937).

This submerged land mass would appear to have played a very great part in the dispersal of the Oriental fauna to Africa and the present discontinuity in the distribution of the Clariidae could be partly explained as the result of submergence of this land mass. Much evidence for this route is afforded by the fauna of Sokotra, which is more Indian in its composition than African.

Hora (1944) traced the centre of origin of the fresh-water fish fauna of South-East Asia to South China, particularly the table land of Yunnan. He stated:

'I have referred above to the differential movements that produced the high peaks of the Sikkim Himalayas, prevented the migration of torrential fishes to the western parts of the range and deflected it along the Satpura trend. As pointed out by Krishnan and Aiyengar, these movements were from two sides, one from the north and one from the east. The thrust from the east probably produced a downward block-faulting and buckling in the Satpura trend and thus made it possible for the north-eastern fishes to spread



TEXT-FIG. 4. Hypothetical map of S. Asia and Africa (constructed after Wiseman and Sewell 1937) showing the route of migration of Clariidae.

to the south-west. Gregory and Gregory (1923) in their work on 'The Alps of Chinese Tibet and their Geographical Relations' and Gregory's (1925) studies on 'The Evolution of the River system in South-Eastern Asia' have also shown that from Yunnan south-westwards the rivers on the west beheaded the rivers on the east. There is a considerable amount of Zoogeographical evidence based on the distribution of hill-stream and other fresh-water fishes which shows that the fish-fauna of India probably migrated from the South Chinese territory.'

The present-day distribution pattern of the family lends support to Hora's (1937, p. 354-55) assumption that the ancestral home of the Clariidae was in South China.

CONCLUSION

To sum up it may be stated that the evidences provided by the palaeontological and distributional records indicate that the family originated somewhere in South China during the Early Pliocene period, when the Siwalik climatological conditions extended as far east as China and beyond Baluchistan towards the west, and thence spread to India and Africa on the one hand and to the other parts of the South-East Asia on the other. The present-day distribution of *Heterobranchus* and *Clarias*, the two oldest genera of the family in the Oriental and the Ethiopian regions and their occurrence in the Siwalik deposits in India clearly show that in earlier times they were more widely distributed and continuously.

The absence of the family from countries between India and Africa at present is due to the retreat of the favourable Siwalik conditions from there and the gradual drying up of the areas. The present discontinuity can also partly be explained as the result of submergence of the Pliocene land mass that bridged the East African coast with the west coast of India. This submerged land mass would have played a very great part in the dispersal of the Oriental fauna to Africa. The distributional study of Clariidae also enables us to conclude that there is little Ethiopian element in the fresh-water fish fauna of India, and that there is a predominant Indian element in the fauna of Africa.

ACKNOWLEDGEMENTS.

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RADIOACTIVITIES OF SILVER BY IRRADIATION WITH FAST NEUTRONS FROM THE Ra+Be-SOURCE

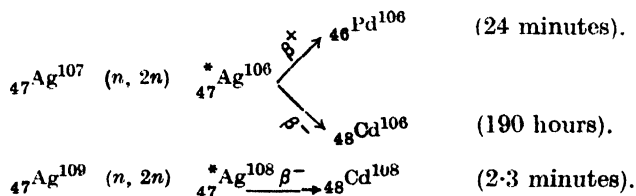
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1. INTRODUCTION.

Silver possesses the two isotopes 107 and 109 in the proportion 52.5% and 47.5% respectively. By simple capture of slow neutrons these give rise to Ag^{108} and Ag^{110} with intense radioactivities of 2.3 minutes and 22 seconds periods respectively. With fast neutrons, reactions of the type $(n, 2n)$ are likely to occur in silver resulting in the formation of Ag^{106} from Ag^{107} , and Ag^{108} from Ag^{109} according to the following scheme (Pool 1938; Pool, Cork and Thornton 1937):



Ag^{107} produces by the $(n, 2n)$ reaction the isomeric nucleus $^*\text{Ag}^{106}$ which decays by positron emission into Pd^{106} with the period 24 minutes and by electron emission into Cd^{106} with the period 190 hours. Similarly the isotope 109 produces Ag^{108} by the same reaction, which, as is well known, decays by electron emission with 2.3 minutes period into Cd^{108} . Viewing the $(n, 2n)$ reaction by fast neutrons as a process analogous to the ionisation of an atom by electron collision as in Franck and Hertz's experiment, only very fast neutrons having energies greater than the binding energy of the neutron in the nucleus ($E_n \sim 6$ to 8 Mev.) are likely to produce the reaction (Teucher 1949), and it is expected to occur with a cross-section much smaller than that calculated on the orthodox picture of a two stage nuclear reaction through the formation of the compound nucleus (Weisskopf, 1950).

The two long periods of radiosilver 106 mentioned above, 24 minutes and 190 hours, have been observed by many workers. This isomer is best produced (Pool, Cork and Thornton, 1937) by irradiating silver with fast neutrons from B or Li bombarded by 6 Mev. deuterons from the cyclotron, the neutrons possessing a maximum energy of ~ 20 Mev. The next best method (Kraus and Cork, 1937) has been found to be the neutron bombardment of palladium, $\text{Pd}^{105} (d, n) \text{Ag}^{106}$, using 6.3 Mev. deuterons from the cyclotron. Various cross reactions also have been used for producing the nucleus Ag^{106} and checking the two periods under question. For example, rhodium bombarded with 12 Mev. α -particles from cyclotron (Pool, Cork and Thornton, 1937) shows a feeble activity of 24 minutes of Ag^{106} produced by the reaction $\text{Rh}^{103} (\alpha, n) \text{Ag}^{106}$. An 8.2 day Ag activity has also been clearly observed from this reaction (Hurst and Pool, 1944). Fast neutron (from cyclotron) bombardment of cadmium produces the reaction Cd^{106}

(n, p) Ag^{106} giving the above activities feebly. Bombardment of palladium by 4 Mev. protons has also yielded the 24 minutes period by the reaction $\text{Pd}^{106}(p, n)\text{Ag}^{106}$. Bothe and Gentner (1937) have observed fairly strong activities of 2.3 minutes and 24 ± 1.2 minutes periods by irradiating silver with 17 Mev. γ -rays from $\text{Li} + p$; but no trace of the 22 seconds period was produced in the process, as is expected. Attempts at producing the Ag^{106} isomer by using fast neutrons from the $\text{Ra} + \text{Be}$ source or the $\text{Rn} + \text{Be}$ source have, however, resulted only in the 24 minutes period with weak intensity; no definite evidence of the 190 hours period of the isomer was available (Rotblat, 1937; Reddemann and Strassmann, 1937).

The total flux of the fast neutrons obtained from the cyclotron is indeed much larger than in any ordinary $\text{Ra} + \text{Be}$ source. The latter neutrons have got a maximum energy of about 10.5 Mev. and an average energy lying roughly between 3 and 8 Mev. (Teucher, 1949). The reason that the long periods, 24 minutes and 190 hours, of Ag^{106} are not developed strongly with the $\text{Ra} + \text{Be}$ neutrons, therefore, appears to be that these periods can be excited only by very fast neutrons, probably lying towards the upper limit of the $\text{Ra} + \text{Be}$ neutron energy spectrum. It was, therefore, considered worth while to use the 100 mgm. $\text{Ra} + \text{Be}$ neutron source available in this laboratory to irradiate silver samples and to examine critically if the radiosilver 106 develops under suitable conditions with any reasonable intensity. The energy region of neutron spectrum exciting the isomer 106 is also roughly investigated by varying the condition of exposure. Results of such observations may find their application in the possibility that if it is confirmed that very fast neutrons alone can excite the 24 minutes period, this activity of silver may be used as an indicator of fast neutrons in other reactions. Attempt is also made in the present work to estimate roughly from the observed data the contributions of the fast and the slow neutrons to the various periods of radiosilver.

2. EXPERIMENTAL ARRANGEMENT AND RESULTS.

As mentioned in the previous section, we expect the intensity of the 24 minutes activity of Ag^{106} to be very feeble, if it is developed at all, by the bombardment of silver by neutrons from the $\text{Ra} + \text{Be}$ source. Hence it is important that the activity is not further reduced to any appreciable extent by the measuring arrangement. Moreover, we also wish to observe the shorter period activities (22 seconds and 2.3 minutes) as an indicator for the presence of slow neutrons in the source. In view of these two requisites a G.M. tube counter with silver cathode has been used in the present work. Here the counter acts as the detector of its own activity. The cylindrical silver cathode was 7.7 cms. in length and 2.5 cms. in internal diameter and ~ 0.5 mms. wall thickness. A tungsten wire (diameter 0.2 mm.) was used as the anode. The counter was filled with 7 cms. Hg pressure of argon and 1 cm. Hg pressure of alcohol. The threshold of the counter was about 1,300 volts and the plateau region extended over 150 volts. The counter background was about 20 ± 1 counts per minute under 10 cms. lead enclosure and this remained practically constant throughout the experiment. An ordinary resistance-capacity coupled amplifier was used together with a cyclotron pulse counter. A stabilised H.T. source developed in this laboratory (Saha, Chandrasekhara and Sundaresan, 1950) provided the counter-potential.

The silver activities were measured as they developed under various conditions of neutron irradiation detailed in Table I. A typical arrangement for irradiation with slow neutrons using 10 cms. paraffin wax all round the $\text{Ra} + \text{Be}$ source is shown in Fig. 1. Fig. 2 B, A, C illustrate the observations on 2.3 minutes period of silver with very fast, medium slow and very slow neutrons respectively under conditions specified as cases 1, 2, 3 in column 2 of Table I. Fig. 3 B, A illustrate the corresponding observations on the 24 minute period of silver developed under the first two conditions (cases 1 and 2) respectively. Fig. 3 C refers to the case 3

above. The dots represent the observed counts and the crosses the calculated decay of the 2.3 minute period starting with the same initial intensity as that obtained by extrapolating the observed counts to zero time. It is seen that the observed intensities agree well with the calculated values till the observed counts fall to the constant background indicated by the horizontal tail. This proves that under this condition (case 3), no 24 minute period is developed within the limits of experimental error.

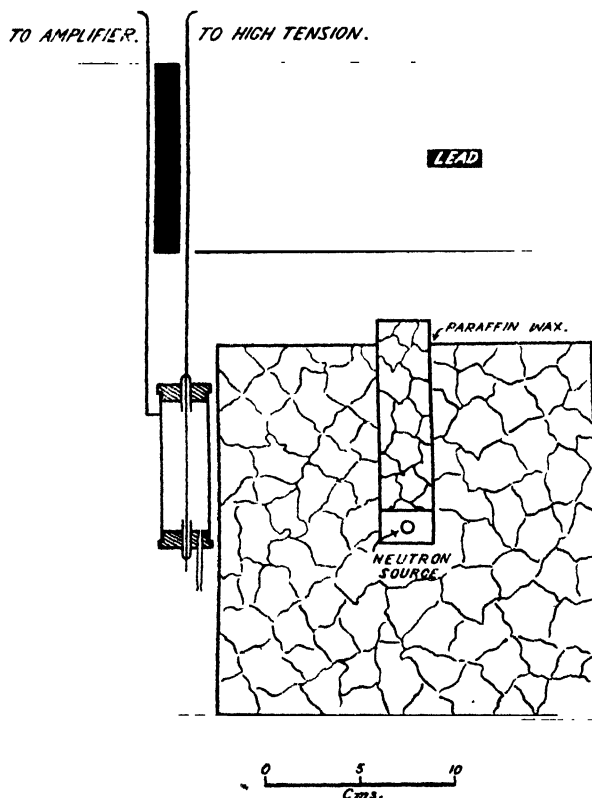


FIG. 1. Experimental arrangement with 10 cms. of paraffin wax (case 2).

As the distances (shown in column 3) between the source and the counter are different under the different conditions of exposure the readings are all to be converted to the same geometry. Considering the neutron source as a point source situated at a distance p on the perpendicular bisector of the axis of the counter and replacing the counter by a rectangular area having breadth $2b$ (the same as the counter diameter) and length $2l$ (the same as the counter length) normal to p at the axis of the counter, the solid angle subtended by the rectangle at the point source is given by the formula

$$\Omega = 4 \tan^{-1} l \cdot b / p(p^2 + l^2 + b^2)^{\frac{1}{2}}$$

All readings for the 2.3 minutes period activity are converted to the same solid angle as that in case 2, Table I, by using the above formula and the converted readings are shown in column 7 of the Table. The 24 minutes period readings are not converted, since no quantitative conclusions are drawn from their intensities under the different conditions of exposure.

TABLE I
(The counts recorded are all for 15 minutes)

1	2	3	4	5	6	7
Case	Condition of irradiation of the counter	Distance p	22 secs. intensity	2-3 mins. intensity	24 mins. intensity	2-3 mins. intensity converted to the same geometry as in case 2.
(1)	n -source filtered through 1 mm. of Cd placed in contact with the counter inside a 10 cms. lead enclosure.	3.1 cms.	very weak.	moderately strong; 7,079 counts.	present; 170 ± 18 counts.	787 counts.
(2)	n -source placed at the centre of a paraffin cylinder 20 cms. dia. and 20 cms. ht.; the counter is just outside the cylinder and the whole enclosed in 10 cms. lead.	11.3 cms.	very strong; not resolved.	very strong; 15,850 counts.	present as before; 200 ± 20 counts.	15,850 counts.
(3)	An additional paraffin block 8 cms. thick, 10 cms. wide and 20 cms. ht. is placed between the wax cylinder in case (2) and the counter, giving a total paraffin wax thickness of 18 cms. between the counter and the source. The whole is enclosed in 10 cms. lead.	19.3 cms.	very strong; not resolved.	moderately strong; 9,290 counts.*	absent within limits of experimental error.	26,012 counts.

* Calculated from the observed activity of 3,715 counts in 6 minutes.

FIG. 2. Development of the 2.3 minute period of silver.

- A. Slow neutron irradiation of silver under 10 cms. of paraffin wax (case 2) (counts in 15 minutes).
 B. Fast neutron irradiation of silver through 1 mm. cadmium (case 1) (counts in 15 minutes).
 C. Very slow neutron irradiation of silver under 18 cms. of paraffin wax (case 3) (counts in 6 minutes).

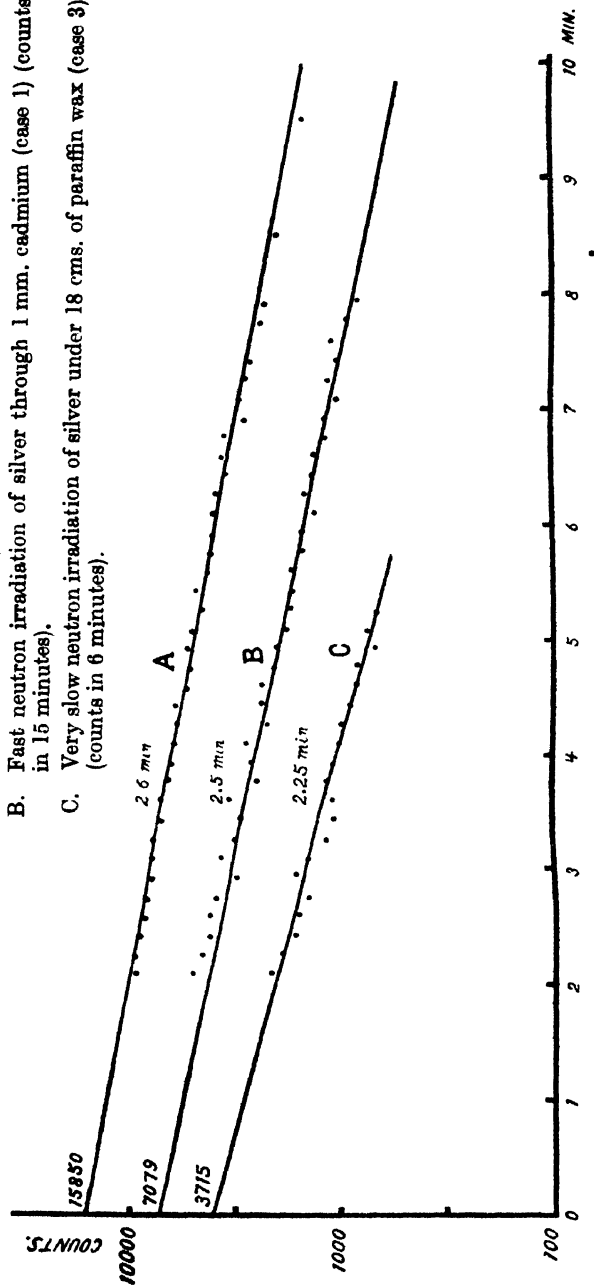
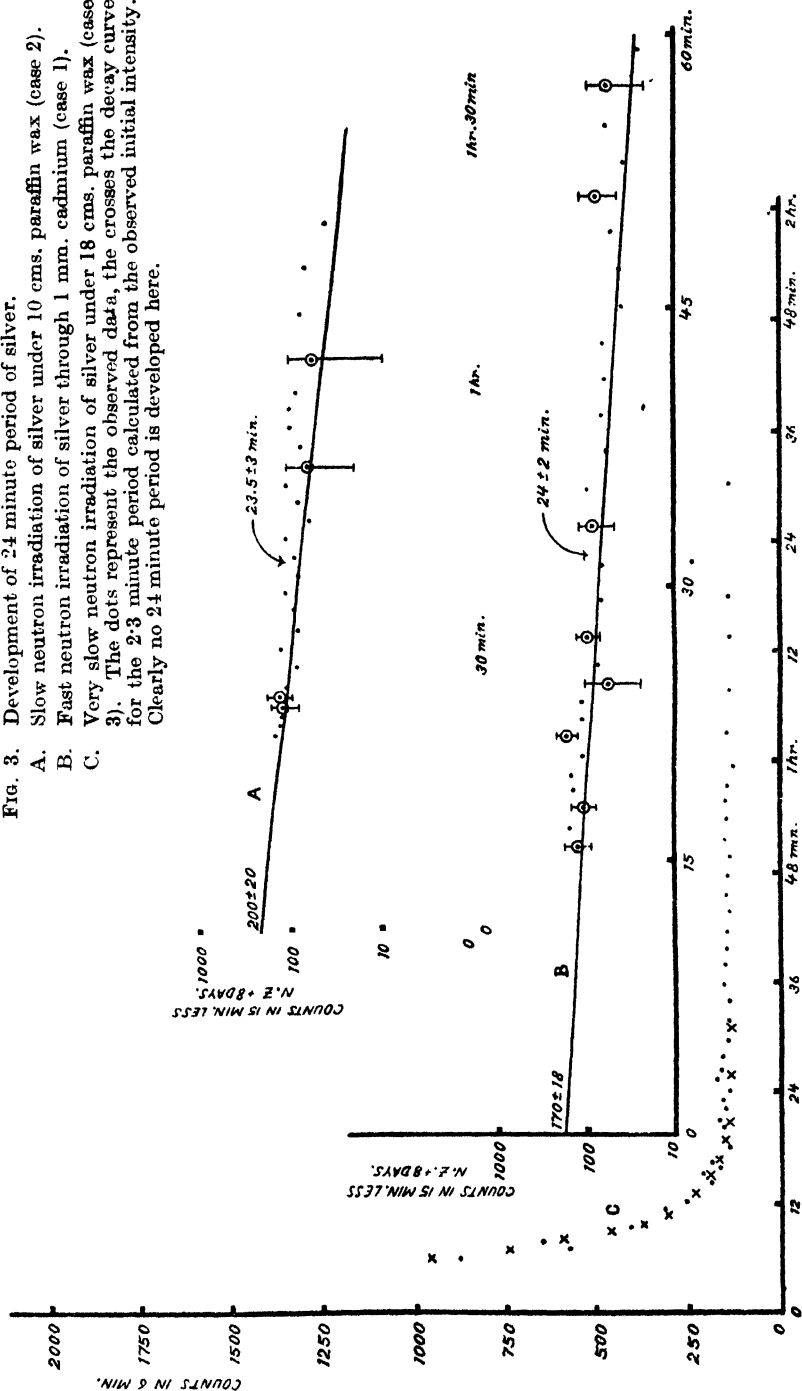


Fig. 3. Development of 24 minute period of silver.

- A. Slow neutron irradiation of silver under 10 cms. paraffin wax (case 2).
 B. Fast neutron irradiation of silver through 1 mm. cadmium (case 1).
 C. Very slow neutron irradiation of silver under 18 cms. paraffin wax (case 3). The dots represent the observed data, the crosses the decay curve for the 2.3 minute period calculated from the observed initial intensity. Clearly no 24 minute period is developed here.



3. DISCUSSION.

It is clear from the results that the 24 minutes period activity is developed only under conditions 1 and 2, i.e., in the case of fast neutrons filtered through 1 mm. cadmium and of slow neutrons produced under 10 cms. paraffin wax, with an intensity much lower than that of either the 22 seconds or the 2.3 minutes period activity of silver. There is not much change in the intensity of the 24 minutes period activity in the two cases, thereby indicating that 10 cms. of wax transmit nearly all the fast neutrons responsible for the $\text{Ag}^{107} (n, 2n) \text{Ag}^{106}$ reaction. On the other hand, in the case 3 the introduction of the additional 8 cms. layer of wax between the 10 cms. radius wax cylinder and the counter almost completely cuts down the 24 minutes period activity within limits of experimental error. It will, therefore, be reasonable to conclude that the fast neutrons taking part in the $(n, 2n)$ reaction in Ag^{107} are in the region of the upper limit of the neutron spectrum from the Ra+Be source. Nothing can be inferred about the actual energy of these neutrons from the present measurements.

By comparing the results under conditions (1) and (2) in the last column of Table 1, it seems possible to separate the contributions of slow and of fast neutrons to the production of the 2.3 minutes period activity. We see that 787 counts of this activity are produced after filtering the neutrons through 1 mm. of cadmium. On the other hand, the activity of the 22 seconds period is observed to develop with a very feeble intensity under the same condition of irradiation, probably due to the back scattering of the transmitted neutrons. This suggests that slow neutrons are practically completely cut off by the 1 mm. cadmium filter and the activity of the 2.3 minute period observed is wholly due to the fast neutrons transmitted by the cadmium. To check this point and to ascertain whether these 787 counts are due to the fast neutrons alone, the cadmium filter was surrounded by a silver filter (resonance) 0.5 mm. thick and the observations were repeated (results not shown in the Table). The activities observed were practically identical with those of case 1. This definitely excludes the possibility of any slow neutrons emerging from the cadmium filter and establishes that the 787 counts are due to the fast neutrons alone, producing the reaction $\text{Ag}^{109} (n, 2n) \text{Ag}^{108}$. It is possible that these fast neutrons are also roughly in the same region of energy of the neutron spectrum of the Ra+Be source as those producing the 24 minutes period activity by the $\text{Ag}^{107} (n, 2n) \text{Ag}^{106}$ process. Under this assumption we may thus conclude that in case 2, out of the 15,850 counts due to the 2.3 minutes period activity, 787 are due to the fast neutrons. In other words, the large activity of the 2.3 min. period generally produced in silver by the Ra+Be neutrons slowed down by 10 cms. of paraffin wax is not wholly attributable to slow neutrons; but about 5% of the observed activity is due to the fast neutrons of the source transmitted by the 10 cms. paraffin, having energies towards the upper limit of the neutron energy spectrum from this source.

Though a quantitative calculation of the relative cross-sections of the two periods made from the present data cannot be relied upon too much, since disturbing effects, such as back scattering, have not been eliminated in the experimental arrangement, yet a rough estimate of these is probably permissible. Thus, subtracting the 787 counts due to the 2.3 minutes period activity produced by the fast neutrons from the total 15,850 counts due to both fast and slow neutrons obtained in case 2, we get the 2.3 minute period intensity due to the slow neutrons alone as 15,063 counts. The fast neutrons exciting the 2.3 minutes period activity in case 2, when converted fully to slow neutrons by an additional 8 cms. of wax in case 3 gives the additional counts $(26,012 - 15,063) = 10,949$. In this we assume that the additional 8 cms. of wax does not reduce the intensity of the slow neutrons produced by the 10 cms. of wax by any appreciable amount. This assumption is justified, since the 8 cms. of wax is inserted only between the counter and the source

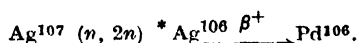
on one side of the 10 cms. radius wax cylinder, just covering the length of the counter. This extra thickness when distributed uniformly all round the wax cylinder of 10 cms. radius and 20 cms. height, would come only to an equivalent increase in the diameter of the cylinder by about 0.8 cm. This increase will not reduce the intensity of the slow neutrons transmitted by the 10 cms. wax cylinder by more than 0.9% (Dunning, Pegram, Fink and Mitchell, 1935). We can, therefore, conclude that the cross-section of the 2.3 minutes period activity for the fast and the slow neutrons are roughly in the ratio 787 : 10,949, i.e., roughly as 1 : 14.

From columns 5 and 6 of Table I, we see that with 1 mm. thick cadmium filter (case 1) transmitting only fast neutrons, there are 7,079 counts due to the 2.3 minutes period activity and 170 ± 18 counts due to the 24 minutes period activity under identical conditions of irradiation. Hence we may conclude that the relative yield of the 24 minutes period process to the 2.3 minutes period process produced by the fast neutrons is roughly as 1 to 42.

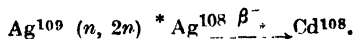
As already shown, the slow neutrons emerging from the 10 cms. wax cylinder produce 15,063 counts due to the 2.3 minutes period activity. The fast neutrons of case 1, responsible for the 787 counts of the 2.3 minutes period activity, may also be assumed to emerge practically unchanged from the 10 cms. wax cylinder in case 2. These when fully converted to slow neutrons by an additional layer of 8 cms. of wax (case 3), produce 10,949 counts of the 2.3 minute period. From this it follows that about $(10,949/15,063) \times 100$ or roughly 73% of the neutrons emerging from the 10 cms. wax cylinder are slow neutrons of the energy region which produces the 2.3 min. period activity of Ag.

SUMMARY.

Neutrons from a 100 mgm. Ra+Be source are used to irradiate the silver cathode of a G-M counter and the 22 seconds, 2.3 minutes and 24 minutes periods of radiosilver are studied. The 24 minutes period activity is due to the silver isomer Ag^{106} produced by the reaction



The 2.3 minutes period due to Ag^{108} can be produced by the simple capture of slow neutrons in Ag^{107} or by the reaction



From the observations on the relative intensities of the periods developed under different conditions of irradiation it is proved qualitatively that:

1. The 24 minute period activity (Ag^{106}) is produced only by very fast neutrons towards the upper limit of the Ra+Be neutron energy spectrum.
2. About 5% of the usually observed 2.3 minute period activity with neutrons slowed down by 10 cms. of paraffin wax is due to the fast neutrons transmitted by the wax.
3. The cross-sections of the 2.3 minutes period activity for the fast and the slow neutrons are roughly in the ratio 1 : 14.
4. The relative yield of the 24 minutes period process to the 2.3 minutes period process produced by fast neutrons is roughly 1 to 42.
5. Roughly about 73% of the neutrons emerging from the 10 cms. wax cylinder are slow neutrons (producing the 2.3 minute period activity of Ag).

We take this opportunity to express our sincere thanks to Dr. R. C. Majumdar, Head of the Department of Physics for giving us the facilities for carrying out this work in the Physics Laboratories and for many helpful discussions.

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THE RÔLE OF THE THREE-INDEX SYMBOLS IN RELATIVITY.

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1. INTRODUCTION.

For the Riemannian metric of general relativity, viz.,

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu, \quad \dots \quad \dots \quad \dots \quad (1)$$

the Christoffel three-index symbols are

$$\left\{ \alpha\beta, \gamma \right\} = \frac{1}{2} \left(\frac{\partial g_{\alpha\gamma}}{\partial x^\beta} + \frac{\partial g_{\beta\gamma}}{\partial x^\alpha} - \frac{\partial g_{\alpha\beta}}{\partial x^\gamma} \right) \quad \dots \quad \dots \quad \dots \quad (2)$$

and
$$\left\{ \begin{smallmatrix} \lambda \\ \alpha\beta \end{smallmatrix} \right\} = g^{\lambda\gamma} \left\{ \alpha\beta, \gamma \right\}. \quad \dots \quad \dots \quad \dots \quad (3)$$

In the following we will consider Christoffel three-index symbols of the type (3) and certain other symbols having a similar set of upper and lower suffixes. In general relativity the symbols appear in the equations of the geodesics, viz.,

$$\frac{d^2 x^\mu}{ds^2} + \left\{ \begin{smallmatrix} \mu \\ \alpha\beta \end{smallmatrix} \right\} \frac{dx^\alpha}{ds} \cdot \frac{dx^\beta}{ds} = 0, \quad \dots \quad \dots \quad \dots \quad (4)$$

and also in the field equations through

$$R_{ijk}^h = \frac{\partial}{\partial x^j} \left\{ \begin{smallmatrix} h \\ ik \end{smallmatrix} \right\} - \frac{\partial}{\partial x^k} \left\{ \begin{smallmatrix} h \\ ij \end{smallmatrix} \right\} + \left\{ \begin{smallmatrix} h \\ ja \end{smallmatrix} \right\} \left\{ \begin{smallmatrix} a \\ ik \end{smallmatrix} \right\} - \left\{ \begin{smallmatrix} h \\ ka \end{smallmatrix} \right\} \left\{ \begin{smallmatrix} a \\ ij \end{smallmatrix} \right\}, \quad \dots \quad \dots \quad (5)$$

and

$$R_{ij} = \frac{\partial}{\partial x^j} \left\{ \begin{smallmatrix} h \\ ih \end{smallmatrix} \right\} - \frac{\partial}{\partial x^h} \left\{ \begin{smallmatrix} h \\ ij \end{smallmatrix} \right\} + \left\{ \begin{smallmatrix} h \\ ja \end{smallmatrix} \right\} \left\{ \begin{smallmatrix} a \\ ih \end{smallmatrix} \right\} - \left\{ \begin{smallmatrix} h \\ ha \end{smallmatrix} \right\} \left\{ \begin{smallmatrix} a \\ ij \end{smallmatrix} \right\}. \quad \dots \quad \dots \quad (6)$$

The gravitational field is characterised by

$$R_{ijk}^h \neq 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

there being further restrictions on R_{ij} , which is required to be zero outside matter and non-zero at every point occupied by matter. Thus the importance of the three-index symbols in the theory is obvious but one cannot overlook the fact that they are not tensors. The law of transformation for them is

$$\left\{ \begin{smallmatrix} \gamma \\ \alpha\beta \end{smallmatrix} \right\}' = \left\{ \begin{smallmatrix} c \\ ab \end{smallmatrix} \right\} \frac{\partial x^a}{\partial x'^\alpha} \cdot \frac{\partial x^b}{\partial x'^\beta} \cdot \frac{\partial x'^\gamma}{\partial x^c} + \frac{\partial^2 x^c}{\partial x'^\alpha \partial x'^\beta} \cdot \frac{\partial x'^\gamma}{\partial x^c}. \quad \dots \quad \dots \quad (8)$$

It follows from the structure of (8) that even if $\left\{ \begin{smallmatrix} \gamma \\ \alpha\beta \end{smallmatrix} \right\}$ is not a tensor the difference of two such symbols is a tensor. Thus if $\Gamma_{\alpha\beta}^\gamma$ corresponds to another metric,

$$ds^2 = \gamma_{\mu\nu} dx^\mu dx^\nu, \quad \dots \quad \dots \quad \dots \quad (9)$$

one can see that

$$\left\{ \begin{matrix} \gamma \\ \alpha\beta \end{matrix} \right\} - \Gamma_{\alpha\beta}^{\gamma} \equiv \Delta_{\alpha\beta}^{\gamma} \quad \dots \quad \dots \quad \dots \quad (10)$$

is a tensor.

It is necessary to note that the gravitational field is supposed to be determined when a set of partial differential equations is solved, subject to certain boundary conditions, for the tensor components $g_{\mu\nu}$. The three-index symbols, of which only forty are distinct for a Riemannian metric, are given by (3).

The Newtonian theory of gravitation is based on the conception of action at a distance. It is well-known how the efforts to justify this apparently irrational concept through the existence of a mechanical aether have failed. There is a principle known as the principle of contiguity which postulates that 'cause and effect must be in spatial contact or connected by a chain of intermediate things in contact' (Born, 1949). The field theory which replaces the Newtonian theory and does away with the aether is founded on the principle of contiguity. Instead of considering aether and its properties all over space we have now to consider what happens at a point and in its neighbourhood. Given a vector field ξ^{μ} , the variation from $P(x^{\mu})$ to $Q(x^{\mu} + \delta x^{\mu})$ is defined by the affine connection symbols $L_{\alpha\beta}^{\mu}$ so that

$$\delta \xi^{\mu} = -L_{\alpha\beta}^{\mu} \xi^{\alpha} \delta x^{\beta}. \quad \dots \quad \dots \quad \dots \quad (11)$$

Similarly for a covariant vector field η_{μ} :

$$\delta \eta_{\mu} = L_{\mu\beta}^{\alpha} \eta_{\alpha} \delta x^{\beta}. \quad \dots \quad \dots \quad \dots \quad (12)$$

We find that the affine symbol plays a fundamental part in defining the neighbourhood of a point, or in determining what happens in the neighbourhood of a point. Instead of the aether problems we have now to study the properties of the affine symbols. The metric may or may not exist. If it exists we have the familiar Christoffel three-index symbols. In the first part of this investigation the metric is supposed to exist. To be more precise, we consider a Riemannian metric as given by (1) side by side with a flat space-time metric as given by (9). The Δ -symbols defined by (10) are now tensors. In the second part we introduce the b -symbols which are more general than the Δ -symbols inasmuch as they are not related to a Riemannian metric. Thus there is no metric such as (1) in this treatment. The procedure adopted in the first part helps us to analyse the tensor field of gravitation into parts which are recognisable as close analogues of the classical gravitational field and the results of the second part show that a generalisation is possible, consistent with the inverse-square law of gravitation without having to postulate a Riemannian metric for space-time. As a new derivation of the inverse-square law of gravitation this method must be more fully examined and explored.

In the general theory of relativity there is a certain amount of ambiguity arising out of the fourfold arbitrariness of the co-ordinate system. At the stage where theory makes contact with observation an ambiguity confronts us which throws serious doubts on the ultimate usefulness of the theory. Let us consider Schwarzschild's external solution,

$$ds^2 = -(1-2m/r)^{-1} dr^2 - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 + (1-2m/r) dt^2, \quad \dots \quad (13)$$

which is used for showing that the three crucial tests are satisfied. If we put $m = 0$ in the above we get flat space-time:

$$ds^2 = -dr^2 - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 + dt^2. \quad \dots \quad (14)$$

It is well known that (13) can be expressed in the isotropic form:

$$ds^2 = -(1+m/2r')^4(dx^2+dy^2+dz^2) + \frac{(1-m/2r')^2}{(1+m/2r')^2} dt^2, \quad \dots \quad (15)$$

where $r'^2 = x^2 + y^2 + z^2$.

The transformation which gives (15) from (13) is

$$r = (1+m/2r')^2 r'. \quad \dots \quad (16)$$

If in (15) we put $m = 0$, we get the flat space-time metric

$$d\sigma'^2 = -(dx^2+dy^2+dz^2)+dt^2. \quad \dots \quad (17)$$

It is curious to note that the transformation which carries (13) into (15) transforms (14) into the following:

$$d\sigma^2 = -(1-m^2/4r'^2)^2 dr'^2 - (1+m/2r')^4 r'^2 d\theta^2 \\ - (1+m/2r')^4 r'^2 \sin^2 \theta d\phi^2 + dt^2. \quad \dots \quad (18)$$

If the gravitational field of (13) is to be measured in relation to (14) then it is (18) that serves as the substratum for the gravitational field given by (15). If, on the contrary, (17) is taken as the substratum for (15) then (14) cannot be taken as the substratum for (13). We may consider (13) and (14) as constituting one scheme and (15) and (17) as constituting another, *the two not being equivalent for any discussion of relativistic corrections to Newtonian equations*. As the observables are not necessarily expressible as scalar invariants of the Riemannian metric of the field and as comparison with the corresponding Newtonian results is essential, an auxiliary metric for the flat substratum has to be postulated for the eventual verification of the theoretical predictions. In the arbitrariness of the auxiliary metric is concealed the ghost of indeterminateness of Newton's First Law of Motion.

In the next part we examine how the gravitational effects of a Riemannian metric can be represented by means of the auxiliary metric and certain three-index symbols defined in relation to the two metrics of the field. This work was suggested by Rosen's (1940) investigation on general relativity and flat space.

2. THE Δ -SYMBOLS.

The equations of the geodesics may now be used in the form,

$$\frac{d^2 x^\mu}{ds^2} + \Gamma_{\alpha\beta}^\mu \frac{dx^\alpha}{ds} \cdot \frac{dx^\beta}{ds} = -\Delta_{\alpha\beta}^\mu \frac{dx^\alpha}{ds} \cdot \frac{dx^\beta}{ds}. \quad \dots \quad (19)$$

In a region free from gravitation, the geodesics are given by

$$\frac{d^2 x^\mu}{ds^2} + \Gamma_{\alpha\beta}^\mu \frac{dx^\alpha}{ds} \cdot \frac{dx^\beta}{ds} = 0. \quad \dots \quad (20)$$

Hence the residual term $-\Delta_{\alpha\beta}^\mu \frac{dx^\alpha}{ds} \cdot \frac{dx^\beta}{ds}$ must be responsible for the gravitational effects. By virtue of Weyl's theorem that the Riemannian metric is completely determined when the null and non-null geodesics are given it is clear that all the gravitational effects are derivable from the residual term. Since dx^α/ds is arbitrary the gravitational effects have to be traced to the tensor $\Delta_{\alpha\beta}^\mu$ which has forty distinct components. We have

$$\Delta_{\alpha\beta}^\mu = \frac{1}{2} g^{\mu\lambda} (g_{\alpha\lambda,\beta} + g_{\beta\lambda,\alpha} - g_{\alpha\beta,\lambda}) \quad \dots \quad (21)$$

as given by Rosen (1940). Herein and in what follows the comma (,) preceding a covariant suffix denotes a covariant differentiation with respect to the γ -metric. A covariant differentiation with respect to the g -metric will be denoted by a semi-colon (;) instead of by a comma (,). It may be verified that the right-hand side of (21) is a symmetric tensor in α and β . We have

$$g_{\mu\gamma} \Delta_{\alpha\beta}^{\mu} = \frac{1}{2} (g_{\alpha\gamma, \beta} + g_{\beta\gamma, \alpha} - g_{\alpha\beta, \gamma}). \quad \dots \quad (22)$$

Let us write

$$g_{\mu\gamma} \Delta_{\alpha\beta}^{\mu} = \Delta_{\alpha\beta\gamma}. \quad \dots \quad (23)$$

Hence $\Delta_{\alpha\beta}^{\mu}$ and $\Delta_{\alpha\beta\mu}$ as given by (21) and (23) are associated tensors.

The Δ -tensors thus defined contain only the first order partial derivatives of the metric potentials $g_{\mu\nu}$. Since they are defined in relation to the auxiliary flat metric they would vary with the choice of the auxiliary metric for the same gravitational field. Nevertheless the Δ 's are important and the importance lies in this that the gravitational force of the Newtonian theory appears through them. But gravitation in a field theory is a more complex phenomenon and it is not expressible by a single force-vector. In general relativity the full effect of gravitation is expressed at each point-event through the contracted curvature tensor which is expressible as

$$R_{ij} = \Delta_{hi,j}^h - \Delta_{ij,h}^h + \Delta_{h\alpha}^h \Delta_{ij}^{\alpha} - \Delta_{i\alpha}^h \Delta_{hj}^{\alpha}. \quad \dots \quad (24)$$

The auxiliary metric quantities do not appear explicitly in (24) on account of the convention of the covariant differentiation. But as the auxiliary metric plays an important part in the interpretation of gravitational results we have to consider other differential invariants defined in relation to it and we proceed to consider the following vectors and scalar invariants.

- (i) $R_{\alpha} = \Delta_{\mu\alpha}^{\mu}$,
- (ii) $S_i = \Delta_{\alpha\beta'}^{\mu} g_{\mu i}^{\alpha\beta}$,
- (iii) $L = \Delta_{\mu\alpha}^{\mu} \Delta_{\mu'\beta'}^{\mu'} g^{\alpha\beta}$,
- (iv) $M = \Delta_{\alpha\beta}^{\mu} \Delta_{\alpha'\beta'}^{\mu'} g^{\alpha\beta} g^{\alpha'\beta'} \gamma_{\mu\mu'}$,
- (v) $N = \Delta_{\mu\alpha}^{\mu} \Delta_{\beta\gamma}^{\alpha} \gamma^{\beta\gamma}$,
- (vi) $K = \Delta_{\alpha\beta\gamma} \Delta_{\alpha'\beta'\gamma'}^{\alpha\alpha'} g^{\beta\beta'} g^{\gamma\gamma'}. \quad \dots \quad (25)$

These expressions represent invariant features of relativistic gravitation and in the following we evaluate them for certain well-known line-elements of physical interest. The intensity of gravitation which can be studied only in relation to an auxiliary flat metric is revealed, in a conspicuous manner, by the above vectors and invariants. We have a host of them to study because the tensor character of gravitation cannot be analysed more simply.

(i) The vector, R_{α} :

we have

$$R_{\alpha} = \Delta_{\mu\alpha}^{\mu} = \frac{k_{,\alpha}}{k}, \quad \dots \quad (26)$$

where

$$k = \sqrt{g/\gamma}.$$

We evaluate the vector for three metrics.

(a) Schwarzschild's external line-element.

If we take the line-element (13) with the corresponding flat metric (14) we find $k = 1$. Therefore the four vector-components in this case are

$$R_1 = R_2 = R_3 = R_4 = 0. \quad \dots \quad (27)$$

On the other hand, if we take the line-element in the isotropic form (15), together with the flat metric given by (17), k is not constant and the components of the vector are

$$\begin{aligned} R_1 &= \lambda.mx/2r^3, \quad R_2 = \lambda.my/2r^3 \\ R_3 &= \lambda.mz/2r^3, \quad R_4 = 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad (28) \end{aligned}$$

where

$$\lambda = \frac{3m/r-4}{1-m^2/4r^2}. \quad \dots \quad \dots \quad \dots \quad \dots \quad (29)$$

To the first order of approximation,

$$\begin{aligned} R_1 &= -2mx/r^3, \quad R_2 = -2my/r^3, \\ R_3 &= -2mz/r^3, \quad R_4 = 0. \quad \dots \quad \dots \quad \dots \quad \dots \quad (30) \end{aligned}$$

The vector corresponds to twice the Newtonian force.

(b) Schwarzschild's internal line-element (Tolman, 1934).

$$ds^2 = -(1+r^2/4R^2)^{-2}(dx^2+dy^2+dz^2) + \left[A - \frac{1}{2} \frac{1-r^2/4R^2}{1+r^2/4R^2} \right]^2 dt^2, \quad \dots \quad (31)$$

the corresponding metric for flat substratum being (17). The vector in this case has the components:

$$\begin{aligned} R_1 &= -\lambda x/2R^2, \quad R_2 = -\lambda y/2R^2, \\ R_3 &= -\lambda z/2R^2, \quad R_4 = 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (32) \end{aligned}$$

$$\text{where} \quad \lambda = (1+r^2/4R^2)^{-1} \left[3 - \left\{ A - \frac{1}{2} \frac{1-r^2/4R^2}{1+r^2/4R^2} \right\}^{-1} (1+r^2/4R^2)^{-1} \right]. \quad \dots \quad (33)$$

To the first order the values are

$$R_1 = -x/R^2, \quad R_2 = -y/R^2, \quad R_3 = -z/R^2, \quad R_4 = 0. \quad \dots \quad \dots \quad \dots \quad (34)$$

Since $3/R^2 = 8\pi\rho$, where ρ is the density, we find that R_α stands for twice the Newtonian force in this case as well.

(c) A curious solution (V.V.N. and K.R.K., 1946).

$$ds^2 = -(1+kt)^p dx^2 - (1+kt)^q dy^2 - (1+kt)^r dz^2 + dt^2, \quad \dots \quad \dots \quad (35)$$

where

$$p+q+r = 2, \quad pq+qr+rp = 0,$$

and k is an arbitrary constant. The above is a metric of curved space-time for which the material energy tensor T^ν_μ and the pseudo-energy tensor t^ν_μ are both zero. Taking (17) as the corresponding flat metric we see that the components of the vector are

$$R_1 = R_2 = R_3 = 0, \quad R_4 = \frac{k}{1+kt}. \quad \dots \quad \dots \quad \dots \quad (36)$$

(ii) The vector, S_i :

$$\begin{aligned} S_i &= \Delta_{\alpha\beta}^{\mu} g^{\alpha\beta} g_{\mu i}, \\ &= g^{\alpha\beta} g_{\alpha i, \beta} - \frac{k_{, i}}{k}. \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (37) \end{aligned}$$

In this case also we consider the same three metrics.

(a) Schwarzschild's external line-element.

For the line-element (13) coupled with the flat metric (14) this vector is given by

$$S_i = g^{\alpha\beta} g_{\alpha i, \beta}, \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (38)$$

since $k = 1$. The components are

$$S_1 = (1 - 2m/r)^{-1} (2m/r^2), \quad S_2 = S_3 = S_4 = 0. \quad \dots \quad (39)$$

To the first order of approximation,

$$S_1 = 2m/r^2, \quad S_2 = S_3 = S_4 = 0. \quad \dots \quad \dots \quad \dots \quad (40)$$

This is again proportional to twice the force-vector. If we take the isotropic form (15) and (17) as the corresponding flat metric, the components are

$$S_1 = -\lambda m x / 2r^3, \quad S_2 = -\lambda m y / 2r^3, \quad S_3 = -\lambda m z / 2r^3, \quad S_4 = 0, \quad \dots \quad (41)$$

$$\text{where} \quad \lambda = [4(1 + m/2r)^{-1} + (-4 + 3m/r)(1 - m^2/4r^2)^{-1}]. \quad \dots \quad \dots \quad (42)$$

To the first order,

$$S_1 = S_2 = S_3 = S_4 = 0. \quad \dots \quad \dots \quad \dots \quad \dots \quad (43)$$

It is interesting to see how R_α and S_i vary in the two different schemes for the same gravitational field.

(b) Schwarzschild's internal line-element.

For this case in the isotropic form (31) with the flat metric (17), we obtain

$$S_1 = S_2 = S_3 = S_4 = 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad (44)$$

to the first order. However, if we take the line-element in the other form (Tolman, 1934),

$$\begin{aligned} ds^2 &= -dr^2/(1 - r^2/R^2) - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 \\ &\quad + [A - \frac{1}{2}\sqrt{1 - r^2/R^2}]^2 dt^2, \quad \dots \quad \dots \quad \dots \quad (45) \end{aligned}$$

we obtain

$$S_1 = 5r/2R^2, \quad S_2 = S_3 = S_4 = 0,$$

to the first order.

Here again we see how the vector differs in the two different schemes.

(c) The curious solution.

We have

$$S_1 = S_2 = S_3 = 0, \quad S_4 = -k/(1 + kt). \quad \dots \quad \dots \quad \dots \quad (46)$$

We find that the Newtonian analogues of R_α and S_i both are null force-vectors. R_4 and S_4 have no Newtonian analogues.

(iii) L and M :

The invariants L and M are scalar magnitudes $R^\alpha R_\alpha$ and $S_i S^i$ respectively. The scalar product of R_α and S_i , as given by

$$R_\alpha S_i g^{\alpha i} = \Delta_{\mu\alpha}^\mu \Delta_{jk}^\gamma q^{jk} g_{\gamma i} g^{i\alpha} = \Delta_{\mu\alpha}^\mu \Delta_{jk}^\alpha q^{jk},$$

is equivalent to N to the second order of approximation.

(iv) The invariant, K :

If we confine ourselves to the use of orthogonal cartesian co-ordinates the invariant reduces to

$$K = \frac{1}{4} \gamma^{\alpha\alpha'} \gamma^{\beta\beta'} \gamma^{\gamma\gamma'} \left(3 \frac{\partial g_{\alpha'\gamma'}}{\partial x^{\beta'}} - \frac{\partial g_{\alpha'\beta'}}{\partial x^{\gamma'}} \right) \frac{\partial g_{\alpha\gamma}}{\partial x^\beta}. \quad \dots \quad (47)$$

Performing the summation for the line-element,

$$ds^2 = -A dx^2 - B dy^2 - C dz^2 + D dt^2, \quad \dots \quad (48)$$

A, B, C, D being functions of x, y, z, t , we obtain

$$\begin{aligned} K = \frac{1}{4} [& -A_1^2 - 3A_2^2 - 3A_3^2 + 3A_4^2 \\ & -3B_1^2 - B_2^2 - 3B_3^2 + 3B_4^2 \\ & -3C_1^2 - 3C_2^2 - C_3^2 + 3C_4^2 \\ & -3D_1^2 - 3D_2^2 - 3D_3^2 + D_4^2], \quad \dots \quad (49) \end{aligned}$$

where the lower suffixes 1, 2, 3, 4, denote differentiation with respect to x, y, z, t respectively. For a static line-element in the isotropic form,

$$ds^2 = -P(dx^2 + dy^2 + dz^2) + Q dt^2, \quad \dots \quad (50)$$

$$\begin{aligned} K = -\frac{1}{4} [& 7 \left\{ \left(\frac{\partial P}{\partial x} \right)^2 + \left(\frac{\partial P}{\partial y} \right)^2 + \left(\frac{\partial P}{\partial z} \right)^2 \right\} \\ & + 3 \left\{ \left(\frac{\partial Q}{\partial x} \right)^2 + \left(\frac{\partial Q}{\partial y} \right)^2 + \left(\frac{\partial Q}{\partial z} \right)^2 \right\}]. \quad \dots \quad (51) \end{aligned}$$

We see that K , for a static orthogonal line-element, is always negative. Below are given the values for this invariant for some line-elements of physical interest.

(a) Schwarzschild's external line-element (15).

$$K = -\frac{m^2}{r^4} \left[7 \left(1 + \frac{m}{2r} \right)^6 + 3 \frac{(1 - m/2r)^2}{(1 + m/2r)^6} \right] \quad \dots \quad (52)$$

Retaining only m^2 terms and neglecting higher powers of m we get

$$K = -10m^2/r^4,$$

i.e. $\sqrt{-K}$ is proportional to the field strength.

(b) Schwarzschild's internal line-element (31).

$$K = -\frac{r^2}{4R^4} \left[\left(1 + \frac{r^2}{4R^2} \right)^{-4} \left\{ 7 \left(1 + \frac{r^2}{4R^2} \right)^{-2} + 3 \left(A - \frac{1}{2} \frac{1 - r^2/4R^2}{1 + r^2/4R^2} \right)^2 \right\} \right]. \quad (53)$$

To the first order,

$$K = -10r^2/4R^4$$

$$\text{or } \sqrt{-K} = \sqrt{10r/2R^2} = \sqrt{10} \frac{1}{2} \pi p r. \quad \dots \quad (54)$$

In this case also $\sqrt{-K}$ equals $\sqrt{10}$ times the gravitational field strength.

(c) The two-body line-element (Einstein, Infeld and Hoffmann, 1938).

For the abovementioned line-element we have

$$h_{11} = h_{22} = h_{33} = h_{44} = \lambda^2 \left(-\frac{2m_1}{r_1} - \frac{2m_2}{r_2} \right) + O(\lambda^4),$$

$$h_{\alpha\beta} = O(\lambda^3), \quad h_{\alpha\beta} = O(\lambda^4); \quad \alpha, \beta = 1, 2, 3,$$

$$r_1^2 = (x^1 - \xi^1)^2 + (x^2 - \eta^1)^2 + (x^3 - \zeta^1)^2,$$

$$\text{and } r_2^2 = (x^1 - \xi^2)^2 + (x^2 - \eta^2)^2 + (x^3 - \zeta^2)^2. \quad \dots \quad (55)$$

m_1 and m_2 are mass-constants associated with the points (ξ^1, η^1, ζ^1) and (ξ^2, η^2, ζ^2) respectively. λ is a parameter of expansion of small but definite magnitude. K is given by

$$K = -10\lambda^4 \left[\frac{m_1^2}{r_1^4} + \frac{m_2^2}{r_2^4} + \frac{2m_1m_2}{r_1^3r_2^3} \mathcal{Z}(x^1 - \xi^1)(x^1 - \xi^2) \right. \\ \left. - \frac{m_1^2}{r_1^4} \dot{r}_1^2 - \frac{m_2^2}{r_2^4} \dot{r}_2^2 - \frac{2m_1m_2}{r_1^2r_2^2} \dot{r}_1\dot{r}_2 \right], \quad \dots \quad (56)$$

where a dot denotes a differentiation with respect to 't.' If $\sqrt{-K}$ is treated as proportional to the field strength, as in other cases, we see how the Newtonian expression is modified by velocity terms which are relativistic corrections.

(d) The curious solution.

In this case alone we find that K is positive in contrast to other gravitational fields of physical significance.

$$K = \frac{3}{4} \frac{k^2}{(1+kt)^2} [p^2(1+kt)^{2p} + q^2(1+kt)^{2q} + r^2(1+kt)^{2r}]. \quad \dots \quad (57)$$

It needs to be more fully investigated if the sign of K can furnish a criterion for distinguishing between real and fictitious gravitational fields as given by line-elements which are non-flat.

(e) The line-element,

$$ds^2 = -e^\mu(dx^2 + dy^2 + dz^2 - dt^2), \quad \dots \quad (58)$$

where

$$\mu = \mu(r \pm t).$$

This is an example of a line-element which is non-flat and for which $K = 0$. The line-element is conformal to flat space-time and we have verified that it is devoid of physical significance.

3. A NEW REPRESENTATION OF GRAVITATION.

In the last section we have seen how a Riemannian field can be considered as a field of Δ -symbols superposed on the auxiliary flat space-time. By way of

generalisation we may consider the effect of superposing a field of b -symbols, more general than the Δ -symbols. The generality will consist in this that while

$$\Gamma_{ij}^k + \Delta_{ij}^k = \left\{ \begin{matrix} k \\ ij \end{matrix} \right\} \quad \dots \quad \dots \quad \dots \quad (59)$$

provides a Riemannian field,

$$\Gamma_{ij}^k + b_{ij}^k = \bar{\Gamma}_{ij}^k \quad \dots \quad \dots \quad \dots \quad (60)$$

will not necessarily be equivalent to the Christoffel three-index symbols of a Riemannian metric. In general $\bar{\Gamma}_{ij}^k$ will serve as a symmetric affine connection for non-metric four-space. There are forty distinct components of the b -symbols. One restriction on them will be that if

$$\frac{d^2 x^\mu}{ds^2} + \Gamma_{ij}^\mu \frac{dx^i}{ds} \cdot \frac{dx^j}{ds} = -b_{ij}^\mu \frac{dx^i}{ds} \cdot \frac{dx^j}{ds} \quad \dots \quad \dots \quad (61)$$

is the set of equations for the test particle it must be consistent with the metric relation,

$$\gamma_{\mu\nu} \frac{dx^\mu}{ds} \cdot \frac{dx^\nu}{ds} = 1. \quad \dots \quad \dots \quad \dots \quad (62)$$

Differentiating (62) with respect to s we obtain

$$\frac{\partial \gamma_{ij}}{\partial x^k} \frac{dx^i}{ds} \frac{dx^j}{ds} \frac{dx^k}{ds} + \gamma_{ij} \frac{d^2 x^i}{ds^2} \frac{dx^j}{ds} + \gamma_{ij} \frac{dx^i}{ds} \frac{d^2 x^j}{ds^2} = 0, \quad \dots \quad (63)$$

from which we get, on using (61),

$$(b_{ijk} + b_{jki} + b_{kij}) \frac{dx^i}{ds} \cdot \frac{dx^j}{ds} \frac{dx^k}{ds} = 0, \quad \dots \quad (64)$$

where

$$b_{ijp} = b_{ij}^k \gamma_{pk}. \quad \dots \quad \dots \quad \dots \quad (65)$$

From (64) we get twenty relations between the b -symbols.

$$b_{11}^2 = -2b_{12}^1, \quad b_{22}^1 = -2b_{21}^2, \quad b_{33}^1 = -2b_{13}^3,$$

$$b_{11}^3 = -2b_{13}^1, \quad b_{22}^3 = -2b_{32}^2, \quad b_{33}^2 = -2b_{23}^3,$$

$$b_{11}^4 = 2b_{14}^1, \quad b_{22}^4 = 2b_{42}^2, \quad b_{33}^4 = 2b_{43}^3,$$

$$b_{11}^1 = b_{22}^2 = b_{33}^3 = b_{44}^4 = 0,$$

$$b_{44}^1 = 2b_{14}^4, \quad b_{44}^2 = 2b_{24}^4, \quad b_{44}^3 = 2b_{34}^4,$$

and

$$b_{12}^3 + b_{23}^1 + b_{31}^2 = 0,$$

$$b_{12}^4 - b_{24}^1 - b_{41}^2 = 0,$$

$$b_{23}^4 - b_{34}^2 - b_{42}^3 = 0,$$

$$b_{13}^4 - b_{34}^1 - b_{41}^3 = 0. \quad \dots \quad \dots \quad \dots \quad (66)$$

For further restrictions on the b -symbols we consider the analogue of the curvature tensor for the affine connection $\bar{\Gamma}_{ij}^k$ and obtain

$$\bar{R}_{jkl}^i = R_{jkl}^i + b_{jl,k}^i - b_{jk,l}^i + b_{kk}^i b_{jl}^h - b_{kl}^i b_{jk}^h \dots \quad \dots \quad (67)$$

We have for flat space-time $R_{jkl}^i = 0$ and therefore we adopt the sixteen equations,

$$\bar{R}_{jki}^i = 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad (68)$$

which can be expressed explicitly as

$$b_{ji,k}^i - b_{jk,i}^i + b_{kh}^i b_{ji}^h - b_{ih}^i b_{jk}^h = 0. \quad \dots \quad \dots \quad \dots \quad \dots \quad (69)$$

Thus we obtain thirty-six conditions for the b -symbols. The number of conditions is four less which leaves scope for the fourfold arbitrariness of the co-ordinate system.

We find that there are identities corresponding to Bianchi identities in this case. We have

$$(\bar{R}_{\beta\gamma\delta}^\alpha)_\epsilon + (\bar{R}_{\beta\delta\epsilon}^\alpha)_\gamma + (\bar{R}_{\beta\epsilon\gamma}^\alpha)_\delta = 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad (70)$$

the differentiation being carried out as indicated by the suffix outside the bracket in the usual manner of a non-metric space.

Thus

$$(A^\alpha)_\epsilon = \frac{\partial A^\alpha}{\partial x^\epsilon} + \bar{\Gamma}_{\beta\epsilon}^\alpha A^\beta. \quad \dots \quad \dots \quad \dots \quad \dots \quad (71)$$

A particular first order solution has been found satisfying the equations (66), (69) and (62) and also the identities (70). The metric tensor for the flat space-time has been taken as

$$\gamma_{11} = \gamma_{22} = \gamma_{33} = -\gamma_{44} = -1; \quad \gamma_{ij} = 0, \quad i \neq j, \quad \dots \quad (72)$$

and the b -symbols are given by the following:

$$b_{22}^1 = b_{33}^1 = -\frac{1}{2}b_{44}^1 = -\frac{mx}{2r^3},$$

$$b_{11}^2 = b_{33}^2 = -\frac{1}{2}b_{44}^2 = -my/2r^3,$$

$$b_{11}^3 = b_{22}^3 = -\frac{1}{2}b_{44}^3 = -mz/2r^3,$$

$$b_{14}^2 = b_{24}^1 = \frac{1}{2}b_{12}^4 = -3mxyt/4r^5,$$

$$b_{14}^3 = b_{34}^1 = \frac{1}{2}b_{13}^4 = -3mxzt/4r^5,$$

$$b_{24}^3 = b_{34}^2 = \frac{1}{2}b_{23}^4 = -3myzt/4r^5,$$

$$b_{11}^4 = mt/2r^3 - 3mx^2t/2r^5,$$

$$b_{22}^4 = mt/2r^3 - 3my^2t/2r^5,$$

$$b_{33}^4 = mt/2r^3 - 3mz^2t/2r^5,$$

along with

$$b_{11}^1 = b_{22}^2 = b_{33}^3 = b_{44}^4 = 0,$$

and

$$b_{12}^3 = b_{23}^1 = b_{31}^2 = 0. \quad \dots \quad \dots \quad \dots \quad \dots \quad (73)$$

m^2 is treated as of the second order in the above.

The solution (73) was suggested by the structure of the equations (69). One of us found the same solution independently by considering the question of plane orbits for the test particles. Following the procedure of Narlikar and Karmarkar (1946) we investigate the conditions to be necessarily satisfied by the b -symbols so that the orbit for a test particle is plane.

If x_1, x_2, x_3, x_4 are expressed as x, y, z, t , the condition for plane orbits reduces to

$$\begin{vmatrix} x & y & z \\ \frac{dx}{ds} & \frac{dy}{ds} & \frac{dz}{ds} \\ \frac{d^2x}{ds^2} & \frac{d^2y}{ds^2} & \frac{d^2z}{ds^2} \end{vmatrix} = 0, \quad \dots \quad (74)$$

in which
$$\frac{d^2x}{ds^2} = -b_{ij}^1 \frac{dx^i}{ds} \cdot \frac{dx^j}{ds}, \quad \text{etc.}$$

Together with (66) this condition leads to the following relations:

$$\begin{aligned} b_{11}^3 &= b_{22}^3 = Kz, \\ b_{11}^2 &= b_{33}^2 = Ky, \\ b_{22}^1 &= b_{33}^1 = Kx, \\ b_{44}^1 &= Lx, \quad b_{44}^2 = Ly, \quad b_{44}^3 = Lz, \\ b_{14}^3 &= Az, \quad b_{14}^2 = Ay, \\ b_{24}^1 &= Bx, \quad b_{24}^3 = Bz, \\ b_{34}^1 &= Cx, \quad b_{34}^2 = Cy, \\ b_{11}^4 &= D+2Ax, \quad b_{22}^4 = D+2By, \quad b_{33}^4 = D+2Cz, \\ b_{12}^4 &= Ay+Bx, \quad b_{13}^4 = Cx+Az, \quad b_{23}^4 = Cy+Bz, \quad \dots \quad (75) \end{aligned}$$

where A, B, C, D, L and K are six arbitrary functions of x, y, z, t .

The field conditions (69) can now be used in the form,

$$b_{ji,k}^i - b_{jk,i}^i = 0, \quad \dots \quad (76)$$

so as to get a solution correct to the first order only. The solution (73) given above follows immediately.

For this particular solution the equations of the path of a test particle are found to be in the Cartesian form as follows:

$$\begin{aligned} \ddot{x} + \frac{mx}{r^3} - \frac{m\dot{x}}{2r^3} (2r\dot{t} + t r^2 \dot{\phi}^2 - 2t\dot{r}^2) + \frac{m}{2r^4} (\dot{x}rt - 3x\dot{r}t - r^3 \dot{x}\dot{\phi}) &= 0, \\ \ddot{y} + \frac{my}{r^3} - \frac{m\dot{y}}{2r^3} (2r\dot{t} + t r^2 \dot{\phi}^2 - 2t\dot{r}^2) + \frac{m}{2r^4} (\dot{y}rt - 3y\dot{r}t + r^3 \dot{x}\dot{\phi}) &= 0, \end{aligned}$$

where
$$x^2 + y^2 = r^2, \quad \tan \phi = y/x, \quad \dots \quad (77)$$

and the initial conditions are $z = 0$, $\dot{z} = 0$. The polar form of the equations, if the initial conditions be $\theta = \pi/2$ and $\dot{\theta} = 0$, are

$$r - r\dot{\phi}^2 + \frac{m}{r^2} - \frac{mrt}{2r^3} (r^2\dot{\phi}^2 - 2\dot{r}^2 + 2) - \frac{m}{2r^2} (2\dot{r}^2 + r^2\dot{\phi}^2) = 0,$$

$$\frac{d}{dt} (r^2\dot{\phi}) - \frac{m\dot{\phi}}{2r} [r\dot{r} + t(r^2\dot{\phi}^2 - 2\dot{r}^2 - 1)] = 0. \quad \dots \dots \dots (78)$$

The interesting point about the solution is that it gives the inverse-square law of gravitation without having to modify the conditions of a flat space-time. The non-metric space is purely conceptual and it is to be treated as a logical fiction invented for the purpose of geometrical representation.

SUMMARY.

There is an indeterminateness implicit in the co-ordinates of general relativity. We show how it manifests itself when the gravitational effects are measured in a Riemannian field with an auxiliary flat space-time serving as the substratum. We consider new vectors and scalar invariants, couched in terms of certain three-index symbols which are defined in relation to the auxiliary space-time, and show how the intensity of gravitation appears through them. A new derivation of the inverse-square law of gravitation is given, the space-time being virtually flat. The equations used are of a non-metric affine space and the method is one suggested by the rôle of the three-index symbols in general relativity.

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STABILITY OF TWO STELLAR MODELS WITH VARIABLE Γ .

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In a previous paper (Kushwaha and Bhatnagar, 1951) the stability of the fundamental mode of homogeneous model and the model in which the density varies inversely as the square of the distance from the centre, was considered under the law $\Gamma = \Gamma_0 \left(1 - A \frac{r_0^2}{R^2}\right)$ giving a continuous decrease in Γ , the effective ratio of specific heats for the stellar material, from the centre to the surface of the star. It was inferred there that, contrary to P. Ledoux's statement (1946), that peculiar forms of $\Gamma(r_0)$ will increase the instability, the stability is increased much more than even for the composite two-phase model. In the present note following two models are studied:

- (i) A model with a central point mass equal to one-third of the total mass of the star with homogeneous density distribution throughout the star;
- (ii) Roche-model;

with law of variation for Γ as $\Gamma = \Gamma_0 \left(1 - A \frac{r_0^3}{R^3}\right)$,

where Γ_0 stands for its value at the centre, A is dimensionless constant, r_0 the distance of the point from the centre, R the radius of the star. This choice of the law is made to render the mathematical analysis possible without resorting to numerical integration.

2. For a small radial adiabatic deformation such that

$$\frac{\delta r}{r_0} = \xi(r_0)e^{i\omega t} \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

σ^2 is given by

$$\sigma^2 \int_0^R \xi dI_0 = - \int_0^R 4\pi \xi r_0^3 \frac{d}{dr_0} [(3\Gamma - 4)P_0] dr_0 \quad \dots \quad \dots \quad (2)$$

where suffix zero refers to equilibrium values and

$$I_0 = \int_0^R r_0^2 dm \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

gives the moment of inertia with respect to origin, and ξ is the solution of the differential equation

$$\frac{d^2 \xi}{dr_0^2} + \left[\frac{4 - \mu}{r_0} + \frac{1}{\Gamma} \frac{d\Gamma}{dr_0} \right] \frac{d\xi}{dr_0} + \left[\frac{\sigma^2 \rho_0}{\Gamma P_0} - \frac{\mu}{r_0^2} \left(3 - \frac{4}{\Gamma} \right) + \frac{3}{r_0 \Gamma} \frac{d\Gamma}{dr_0} \right] \xi = 0, \quad \dots \quad (4)$$

with the boundary conditions

$$\xi(r_0) = 0 \text{ at } r_0 = 0, \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

and
$$\delta P = -\Gamma P_0 \left[3\xi + r_0 \frac{d\xi}{dr_0} \right] = 0 \text{ at } r_0 = R, \dots \quad (6)$$

where
$$\mu = G \frac{m(r) \rho_0}{r_0 P_0}. \quad \dots \quad (7)$$

3. MODEL 1.

From (2) it is clear that σ^2 will be positive as long as A lies between zero and $1/5$. Hence, for the fundamental mode the star will definitely be stable for these values of A . To consider for the higher values of A we have to solve the equation (4) actually.

Putting $x = \frac{r_0}{R}$, we have for this model:

$$\Gamma = \Gamma_0(1 - Ax^3), \quad \dots \quad (8)$$

$$\mu = \frac{1 + 2x^3}{1 - x^3}, \quad \dots \quad (9)$$

$$\alpha = \frac{\alpha_0 - 3Ax^3}{1 - Ax^3}, \quad \alpha_0 = 3 - \frac{4}{\Gamma_0}, \quad \dots \quad (10)$$

$$P_0 = \frac{2}{3} \pi G \rho_0^2 R^2 \left(\frac{1}{x} - x^2 \right), \quad \dots \quad (11)$$

$$\bar{\rho} = \frac{3}{2} \rho_0. \quad \dots \quad (12)$$

Substituting these values in (4) we get:

$$(1 - x^3)(1 - Ax^3)\xi'' + [3 - 6(A + 1)x^3 + 9Ax^6] \frac{\xi'}{x} + [Fx^3 - \alpha_0 + 15Ax^6] \frac{\xi}{x^2} = 0, \quad (13)$$

where dashes denote differentiation with respect to x and

$$F = \frac{9\sigma^2}{4\pi G \bar{\rho} \Gamma_0} - 2\alpha_0 - 6A. \quad \dots \quad (14)$$

Equation (13) has regular singularities at $x = 1$ and at $x = \left(\frac{1}{A}\right)^{\frac{1}{3}}$. For our problem

we must have regular integrals which are finite in the range $0 < x < 1$.

The roots of the indicial equation are

$$m = -1 \pm \sqrt{1 + \alpha_0}. \quad \dots \quad (15)$$

To satisfy our physical conditions we have to choose

$$m = \sqrt{1 + \alpha_0} - 1.$$

Putting

$$\xi = x^m \sum_{k=0}^{\infty} a_{3k} x^{3k}, \quad \dots \quad (16)$$

in (13) and equating the coefficients of various powers of x to zero we obtain,

$$\{(m+3)(m+5) - \alpha_0\} a_3 = [(A+1)m(m+5) - F] a_0, \quad \dots \quad (17)$$

and

$$\{(m+3k+3)(m+3k+5)-\alpha_0\}a_{2k+3} = [(A+1)(m+3k)(m+3k+5)-F]a_{2k} - [(m+3k-3)(m+3k+5)+15]Aa_{2k-2}, \dots \quad (18)$$

where $k = 1, 2, 3, 4, \dots$

Writing $\frac{a_{2k+3}}{a_{2k}} = N_{k+1}$, (18) can conveniently be written as

$$N_{k+1} = \frac{(A+1)(m+3k)(m+3k+5)-F}{(m+3k+3)(m+3k+5)-\alpha_0} - \frac{A\{(m+3k-3)(m+3k+5)+15\}}{(m+3k+3)(m+3k+5)-\alpha_0} \frac{1}{N_k}. \quad (19)$$

It is obvious that if $N_k \rightarrow \lambda$ as $k \rightarrow \infty$ then all N_{k+r} ($r = 1, 2, 3, \dots$) tend to λ , where λ is given by

$$\lambda = (A+1) - \frac{A}{\lambda}. \quad \dots \quad \dots \quad \dots \quad \dots \quad (20)$$

This gives $\lambda = 1$ or A . Again we choose our solutions for which $\lambda = A < 1$. For if $N_k \rightarrow 1$ the series for ξ diverges at $x = 1$. Thus restricting ourselves we get a determinate set of values for F .

We can also write (19) in the form

$$N_k = \frac{\frac{A\{(m+3k-3)(m+3k+5)+15\}}{(m+3k+3)(m+3k+5)-\alpha_0}}{\frac{(A+1)(m+3k)(m+3k+5)-F}{(m+3k+3)(m+3k+5)-\alpha_0} - N_{k+1}}. \quad \dots \quad \dots \quad (21)$$

By successive application of this we express N_k in the form of a convergent continued fraction.

$$N_k = \frac{\frac{A\{(m+3k-3)(m+3k+5)+15\}}{(m+3k+3)(m+3k+5)-\alpha_0}}{\frac{(A+1)(m+3k)(m+3k+5)-F}{(m+3k+3)(m+3k+5)-\alpha_0} - \frac{\frac{A\{(m+3k+6)(m+3k+8)+15\}}{(m+3k+6)(m+3k+8)-\alpha_0}}{\frac{(A+1)(m+3k+3)(m+3k+8)-F}{(m+3k+6)(m+3k+8)-\alpha_0} - \frac{\frac{A\{(m+3k+9)(m+3k+11)+15\}}{(m+3k+9)(m+3k+11)-\alpha_0}}{\frac{(A+1)(m+3k+6)(m+3k+11)-F}{(m+3k+9)(m+3k+11)-\alpha_0} - \dots}}}. \quad \dots \quad (22)$$

In particular this will give N_1 , also N_1 is directly obtained from (17) as

$$N_1 = \frac{(A+1) \cdot m(m+5) - F}{(m+3)(m+5) - \alpha_0}. \quad \dots \quad \dots \quad \dots \quad (23)$$

Hence, equating the two values of N_1 we get

$$\frac{F - (A+1) m(m+5)}{(m+3)(m+5) - \alpha_0} + \frac{\frac{A\{m(m+8)+15\}}{(m+6)(m+8) - \alpha_0}}{\frac{(A+1)(m+3)(m+8) - F}{(m+6)(m+8) - \alpha_0} - \frac{\frac{A\{(m+9)(m+11)+15\}}{(m+9)(m+11) - \alpha_0}}{\frac{(A+1)(m+6)(m+11) - F}{(m+9)(m+11) - \alpha_0} - \frac{\frac{A\{(m+12)(m+14)+15\}}{(m+12)(m+14) - \alpha_0}}{\frac{(A+1)(m+9)(m+14) - F}{(m+12)(m+14) - \alpha_0} - \dots}} = 0. \quad \dots \quad (24)$$

This equation gives the value of F , which ultimately gives σ , the frequency of oscillations. The different coefficients in (16) are given by

$$a_{3r} = \prod_1^r (N_s) a_0. \quad \dots \quad (25)$$

Equation (24) is solved by the method indicated in the paper (Kushwaha and Bhatnagar, 1951). The result is tabulated in the table I for $A = 0.1, 0.3, 0.5$ and 0.7 ; and the displacement functions for these different values of A are given below.

$$\left. \begin{aligned} A = 0.1, \xi &= a_0 \{1 + 0.06761x^3 + 0.005079x^6 + 0.000406x^9 + 0.0000339x^{12} + \dots\} \\ A = 0.3, \xi &= a_0 \{1 + 0.2059x^3 + 0.04685x^6 + 0.01132x^9 + 0.002845x^{12} + \dots\} \\ A = 0.5, \xi &= a_0 \{1 + 0.3508x^3 + 0.13507x^6 + 0.05512x^9 + 0.02343x^{12} + \dots\} \\ A = 0.7, \xi &= a_0 \{1 + 0.516x^3 + 0.2898x^6 + 0.17209x^9 + 0.10644x^{12} + \dots\} \end{aligned} \right\} \dots 26$$

TABLE I.

A	F	$y = \frac{9\sigma^2}{4\pi G \bar{\rho} \Gamma_0}$	$\bar{\Gamma} = \int_0^1 \Gamma dx = \Gamma_0 \left(1 - \frac{A}{4}\right)$	Γ_{surface}	x_c
0.1	0.4125	2.2125	1.625	1.5	..
0.3	-1.604	1.396	1.542	1.166	0.874
0.5	-3.7282	0.4718	1.458	0.8333	0.737
0.7	-6.189	-0.789	1.375	0.5	0.654

In this table x_c denotes the value of x such that $\Gamma < \frac{4}{3}$ in the region $x_c < x < 1$. The instability sets in when $\bar{\Gamma} \approx 1.427$ and $x_c \approx 0.703$.

4.

ROCHE-MODEL.

Equation (2) gives σ^2 positive for $0 < A < 1/5$ giving the stability for the fundamental mode for this value of A .

For this model

$$\Gamma = \Gamma_0(1 - Ax^3), \quad \dots \quad (27)$$

$$\rho_0 = \rho_R/x^2, \quad \dots \quad (28)$$

$$g_0 = \frac{GM}{x^2 R^2}, \quad \dots \quad (29)$$

$$P_0 = \frac{GM\rho_R}{3R} \cdot \frac{1-x^3}{x^3}, \quad \dots \quad (30)$$

$$\alpha = \frac{\alpha_0 - 3Ax^3}{1 - Ax^3}, \quad \alpha_0 = 3 - \frac{4}{\Gamma_0}, \quad \dots \quad (31)$$

$$\mu = \frac{3}{1 - x^3}. \quad \dots \quad (32)$$

Substituting these values in (4) we get,

$$(1-x^3)(1-Ax^3)\xi'' + [1-4(A+1)x^3+7Ax^6]\frac{\xi'}{x} + [Fx^3-3\alpha_0+9Ax^6]\frac{\xi}{x^2} = 0, \quad (33)$$

where dashes denote the differentiation with respect to x and

$$F = \frac{9\sigma^2}{4\pi G \bar{\rho} I_0}. \quad \dots \dots \dots (34)$$

Equation (33) has singularities at $x = 1$ and at $x = \left(\frac{1}{A}\right)^{\frac{1}{3}}$. To satisfy the physical conditions we need finite regular solutions in the region $0 < x < 1$.

Roots of the indicial equation for (33) are

$$m = \pm \sqrt{3\alpha_0}. \quad \dots \dots \dots (35)$$

To avoid the singularity at the origin we choose positive sign.
Putting the series

$$\xi = x^m \sum_{k=0}^{\infty} C_{3k} x^{3k}, \quad \dots \dots \dots (36)$$

in (33) and equating the coefficients of different powers of x to zero we have

$$\{(m+3)^2-3\alpha_0\}C_3 = \{(A+1).m(m+3)-F\}C_0, \quad \dots \dots \dots (37)$$

and

$$\begin{aligned} \{(m+3k+3)^2-3\alpha_0\}C_{3k+3} = & [(A+1)(m+3k)(m+3k+3)-F]C_{3k}- \\ & [(m+3k+3)(m+3k-3)+9]AC_{3k-3}, \quad \dots \end{aligned} \quad (38)$$

where $k = 1, 2, 3, 4, \dots$

Writing $\frac{C_{3k+3}}{C_{3k}} = N_{k+1}$, equation (38) can be put in a convenient form as

$$N_{k+1} = \frac{(A+1)(m+3k)(m+3k+3)-F}{(m+3k+3)^2-3\alpha_0} - \frac{A(m+3k)^2}{(m+3k+3)^2-3\alpha_0} \cdot \frac{1}{N_k}. \quad \dots \quad (39)$$

It can easily be seen here that if $N_k \rightarrow \lambda$ as $k \rightarrow \infty$ we have in the limit

$$\lambda = (A+1) - \frac{A}{\lambda}. \quad \dots \dots \dots (40)$$

The roots of this are 1 and A . We restrict ourselves to the solutions for which this limit tends to $A < 1$.

Rewriting (39) in the form

$$N_k = \frac{\frac{(m+3k)^2 A}{(m+3k+3)^2-3\alpha_0}}{\frac{(A+1)(m+3k)(m+3k+3)-F}{(m+3k+3)^2-3\alpha_0} - N_{k+1}}, \quad \dots \dots \quad (41)$$

and applying it successively we can express N_k in a convergent continued fraction.

$$N_k = \frac{\frac{A(m+3k)^2}{(m+3k+3)^2-3\alpha_0}}{(A+1)(m+3k)(m+3k+3)-F} - \frac{\frac{A(m+3k+3)^2}{(m+3k+6)^2-3\alpha_0}}{(A+1)(m+3k+3)(m+3k+6)-F} - \dots \dots \dots (42)$$

$$\frac{\frac{A(m+3k+6)^2}{(m+3k+9)^2-3\alpha_0}}{(A+1)(m+3k+6)(m+3k+9)-F} - \dots \dots \dots$$

In particular we get N_1 from (42). But also from (37)

$$N_1 = \frac{(A+1)(m)(m+3)-F}{(m+3)^2-3\alpha_0} \dots \dots \dots (43)$$

Equating these two values of N_1 we get

$$\frac{F-m(m+3)(A+1)}{(m+3)^2-3\alpha_0} + \frac{\frac{A(m+3)^2}{(m+6)^2-3\alpha_0}}{(A+1)(m+3)(m+6)-F} - \frac{\frac{A(m+6)^2}{(m+9)^2-3\alpha_0}}{(A+1)(m+6)(m+9)-F} - \dots \dots \dots (44)$$

$$\frac{\frac{A(m+9)^2}{(m+12)^2-3\alpha_0}}{(A+1)(m+9)(m+12)-F} - \dots = 0.$$

This equation is solved as before and the results are tabulated in table II, for $A = 0.1, 0.2, 0.5, 0.7, 0.8$ and corresponding displacement functions are obtained as follows.

$$A = 0.1, \xi = a_0 \{ 1 + 0.0728x^3 + 0.005622x^6 + 0.000456x^9 + 0.000038x^{12} + \dots \}$$

$$A = 0.2, \xi = a_0 \{ 1 + 0.1468x^3 + 0.02277x^6 + 0.003706x^9 + 0.000624x^{12} + \dots \}$$

$$A = 0.5, \xi = a_0 \{ 1 + 0.3785x^3 + 0.1499x^6 + 0.06209x^9 + 0.02663x^{12} + \dots \}$$

$$A = 0.7, \xi = a_0 \{ 1 + 0.5572x^3 + 0.32198x^6 + 0.19406x^9 + 0.12109x^{12} + \dots \}$$

$$A = 0.8, \xi = a_0 \{ 1 + 0.67499x^3 + 0.46714x^6 + 0.33489x^9 + 0.24715x^{12} + \dots \}$$

TABLE II.

A	$F = \frac{9\sigma^2}{4\pi G\rho\Gamma_0}$	$\bar{\Gamma} = \int_0^1 \Gamma dx = \Gamma_0 \left(1 - \frac{A}{4}\right)$	Γ_{surface}	x_c
0.1	5.1652	1.625	1.5	—
0.2	4.4869	1.583	1.333	1
0.5	2.283	1.458	0.8333	0.737
0.7	0.4032	1.375	0.5	0.654
0.8	-1.02355	1.333	0.333	0.63

Here the instability sets in where $\bar{\Gamma} \approx 1.364$ and $x_c \approx 0.65$.

5. This shows that in order to render the star dynamically unstable the region where $\Gamma < \frac{4}{3}$ has to extend to an appreciable fraction of the radius. Comparison of the results for these two models for the same law of variation of Γ shows that the increased concentration of mass at the centre favours the stability. Also for all the models it is found that with small continuous variation of Γ the star becomes unstable for much higher value of average Γ than $\frac{4}{3}$. We may assume that this variation of Γ favours instability. Abrupt changes in Γ will make the star more unstable. As the value of Γ depends much upon the degree of ionisation and the presence of elements in the process of ionisation. Hence, vibrational instability may be caused by these internal phenomena also.

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A MORPHOMETRIC AND BIOMETRIC STUDY OF THE SYSTEMATICS OF CERTAIN ALLIED SPECIES OF THE GENUS *BARBUS* CUV. & VAL.*

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INTRODUCTION.

Barbus sarana (Ham.), *B. chrysopoma* Cuv. and Val., *B. caudimarginatus* Blyth, *B. pinnauratus* Day, *B. oatesii* Boulenger, *B. sewelli* Prashad and Mukerji, *B. myitkyinae* Prashad and Mukerji and *B. binduchitra* Hora, form a series of closely allied species (Hora, 1937). Several authors have commented on their close resemblances but their proper taxonomic status has not so far been elucidated. Dr. K. K. Nair suggested to me this problem, and I am grateful to him for the keen interest he took in the progress of this work, and also for placing at my disposal the measurement data of some of the species he had collected. My sincere thanks are due to Dr. S. L. Hora for his guidance and help, and to Dr. J. D. F. Hardenberg for kindly going through the manuscript and making some valuable suggestions.

MATERIAL.

The present work is based on a study of specimens in the collections of the Zoological Survey of India, Calcutta, authentically identified by Ichthyologists like Day, Annandale and Hora and on type specimens of species described by Prashad and Mukerji. Ginsburg (1938) has stressed the necessity of examining a large number of 'constituent samples' in statistical studies in taxonomy. He found that 'specimens in the same lot bearing the same data, evidently having been obtained in one or but a few drags of the net at the same place at the same time, and consequently, most likely having a common immediate genotypic origin, would

* Even though the species referred to here, belong to the sub-genus *Puntius* Ham., they have been generally described under the generic name *Barbus* Cuv. & Val. in Indian literature and so to facilitate references this name has been used in this paper throughout.

tend to group themselves in a predominant manner within a narrowly circumscribed space, sometimes even near either end of the frequency distribution of their species or race as a whole'. This is more clearly discernible in cases where the specimens in the lot are of nearly the same size. It will be evident from the above, that if the sample studied be collected at the same time from the same locality, it is quite likely that in many cases a correct picture of the population would not be obtained. Though the 'sampling' in the present study was limited to the material available, in the majority of cases a nearest approach to the aim has been attempted. All the specimens examined were the ones preserved in alcohol. Only the data obtained from well-preserved specimens has been utilised in this study. Fifty-three specimens, of *B. sarana* (Ham.) collected from Burma, Assam, Bengal, Orissa, Bihar, Punjab, Sind, Bombay and Madras, were examined in detail. Nine specimens of *B. chrysopoma* Cuv. & Val. collected from Coorg (Cauvery river), Lake Beale, Cutch, and Jubbulpore; twenty-one specimens of *Barbus myitkyinae* Prashad and Mukerji obtained from Indawgyi Lake and Kongon Thana (Namya river); 39 specimens of *B. caudimarginatus* Blyth collected from Burma and Manipur; 19 specimens of *B. pinnauratus* Day collected from Bihar and Malaya and 11 specimens of *B. binduchitra* Hora obtained from Sandoway, Burma, were studied. The number of specimens of *B. sewelli* Prashad and Mukerji examined were only two, and of *B. oatesii*, four. The former were obtained from N. Burma and the latter from Manipur.

METHODS.

In classical systematics descriptions of new species have often been based on one or but a very few specimens. When only such a limited number of specimens are examined, closely related populations are likely to appear sharply differentiated as by the law of chance such few individuals are apt to fall in most cases near the centre and away from the extremes of a regular frequency distribution. But modern systematics lay great stress on the range and manner of intraspecific variations. The morphometry of all available material was therefore first studied and the range of variation of characters determined.

Taxonomic characters are generally found to intergrade between closely related populations when a sufficiently large number of individuals are studied in detail. The degree of intergradation varies considerably and the determination whether two populations constitute two distinct species, sub-species, races, etc., is dependent on the degree of intergradation or in other words the degree of divergence.

Different methods of measuring intergradation or divergence have been proposed (Davenport and Blankinship, 1898; Pearl, 1930; Ginsburg, 1938; and Amadon, 1949). Ginsburg (*op. cit.*) used a simple method of measuring the intergradation and divergence of populations and indicated its superiority to the standard methods in taxonomical work. This method consists of determining the point of intersection of the frequency distribution of the characters of two populations, ascertaining the number of individuals of one population that pass to the right of the vertical line drawn from the point of intersection, and the number of individuals of the other population that pass to the left of this line. The simple average of the percentages of such intergrading individuals to the total of each population studied, gives the measure of intergradation of the two populations. Based on this method he designated species, and its sub-divisions as follows: 'Other things being equal, a given population is to be considered a race with respect to another closely related population when the average intergradation of the character showing the greatest divergence is between 30% and 40%; a sub-species constitutes a population intergrading between 15% and 25%; it is to be considered a full species when the degree of intergradation is not more than 10%. Concomitantly, the divergence between races is 60% to 70%, between sub-species 75% to 85% and full species diverge to an extent of 90% or more.'

Instead of determining intergradation or divergence, several workers have based their studies on what is known as 'Probability' which in its numerical expression is often referred to as the 'test of significance'. The taxonomist judges the systematic position of entire populations by the study of relatively restricted samples drawn from them. We know that different samples drawn even from the same variable population may exhibit differences. By this test it can be determined how often such a difference in any given character is likely to be obtained at random, by mere chance, from two samples of the same population. Several authors have employed this method in different forms in their investigations. Dice and Leraas' graphical method as quoted by Hubbs and Perlmutter (1942) has distinct advantages in that it is easier to prepare and can be readily interpreted and compared. Hubbs and Perlmutter (*op. cit.*) improved this method and presented formulae and tables to test the significance accurately. In this method, for each variable character, the range, mean, one standard deviation on each side of the mean, and two standard errors on each side of the mean are delineated on a graph and the significance of difference between samples determined from the degree of overlap or separation of the standard errors of the samples delineated. Even though this technique makes it possible to compare samples with ease and say whether an observed difference is significant or not, it does not indicate definitely whether the difference is of specific, subspecific or racial magnitude. By means of Ginsburg's (*op. cit.*) method the taxonomic rank of two populations can be determined.

In the present study, which as indicated had necessarily to be based on limited samples, it was considered necessary to first ascertain the probability of the samples of the different species being statistically identical with the *B. sarana* samples which showed the greatest range of variation. The reliable characters were compared employing Dice and Leraas' method as improved by Hubbs and Perlmutter (*op. cit.*). In the case of the 2 samples which consisted of only 4 and 2 individuals respectively, this method could not be adopted. Simpson and Roe (1939, pp. 205-209) have given a modified method for the comparison of small samples. This method differs from the conventional method only in that the standard deviation is calculated

by the formula $\sigma = \sqrt{\frac{\Sigma(d^2)}{(N-1)}}$ where

σ is the standard deviation, $\Sigma(d^2)$ is the summation of the squares of the deviation of each observation from the mean and N is the number of individuals in the sample; and P is determined from a special table of t given. This method was employed in comparing these small samples. Where the samples were found to be significantly different from the samples of *B. sarana* the degree of intergradation of characters was examined employing Ginsburg's (*op. cit.*) method and the taxonomic rank determined.

Matsubara (1936 and 1938) in his studies which were very similar to the present one, presented the morphometric data in graphic form. Though his method is not altogether suited to calculate the degree of divergence in exact figures, it gives a fair idea of the relationships of the populations. Further, this method provides an easy means of demonstrating the close resemblance or otherwise of characters. The morphometric characters of the samples examined in this study were therefore presented in the form of scatter diagrams to demonstrate the homogeneity or otherwise of the samples.

REVIEW OF LITERATURE.

Hamilton Buchanan (1822) described for the first time 'a proper *Cyprinus* with four tendrils; with 10 rays in the fin of the back, the longest of the rays being indented behind; with 8 rays in the fin behind the vent; with large scales; with jaws nearly equal; with under lip erect and smooth edged; and with pale fins' from

the Ganges under the name *Cyprinus sarana* and considered it the same as Kunnammoo of Russel (1803). Cuvier and Valenciennes (1842) erected the genus *Barbus* and included *Cyprinus sarana* in this genus under the name *Barbus sarana*. They described another species, *B. chrysopoma* (1842) from the Malabar Coast. From the description it appears that they have distinguished this new species from *B. sarana* (Ham.) by its projecting lower lip and big eyes ($2\frac{1}{2}$ times in the length of head). Jerdon (1849) in his paper 'On the Freshwater Fishes of Southern India' distinguished this species from *B. sarana* (Ham.) by the following characters:

<i>B. sarana</i> (Ham.)	<i>B. chrysopoma</i> Cuv. & Val.
Height 3 times in standard length.	Height $3\frac{1}{2}$ times in standard length.
Ll. 28, Ltr. 9	Ll. 27, Ltr. 10-11
A. 7	A. 8
Bluish above, rest of body yellowish, fins yellowish.	Green above, silvery beneath, a black spot on each side of the tail.

He stated that it is probably nearly allied to *Systemus immaculatus* McClelland and described it as *Systemus chrysopoma* Val. He also observed that it sometimes wants the black spot on the tail. Day (1869) in his paper 'On the fishes of Orissa' treated *Barbus* (*Barbodes*) *sarana* (Ham.) as synonymous with *B. chrysopoma* Cuv. & Val. and *B. russellii* Günther, and stated that *B. sarana* is subject to slight variations in accordance with age, the locality it inhabits and the sex of the specimens.

Bleeker (1853) suggested the probability of *Barbus sarana* (Ham.) being the same as *B. gardonoides* Cuv. & Val., which in his opinion is closely related or probably even identical with *B. rubripinnis* Cuv. & Val., but found Hamilton's description insufficient to decide the question.

Day (1865) described a new species, *Cyclocheilichthys pinnauratus* from a single specimen of the length of $3\frac{4}{10}$ " captured from a small pond in Cochin. Day in his work on the fishes of Malabar (1865) included it in the genus *Puntius* under the name *Puntius pinnauratus*. In his Fishes of India (1878) Day stated that this species and *B. chrysopoma* may be merely varieties of a single species, whilst *B. sarana* (Ham.) is closely allied to it. From Day's descriptions in the Fauna of British India (Fishes, Part I, 1889) the three species can be distinguished by the following characters.

<i>B. sarana</i> (Ham.)	<i>B. chrysopoma</i> Cuv. & Val.	<i>B. pinnauratus</i> Day.
D. 11 (3/8) P. 15 V. 9	D. 12 (4/8) P. 17 V. 9	D. 11 (3/8) P. 17 V. 8
A. 8 (3/5)	A. 8 (3/5)	A. 7 (2/5)
Ll. 32-34.	Ll. 28-30.	Ll. 29-30.
Hd. $5-5\frac{1}{2}$ times in total length.	Hd. $4\frac{1}{2}-5$ times in total length.	Hd. $5-5\frac{1}{2}$ times in total length.
Diameter of eyes $4\frac{1}{2}-4\frac{2}{3}$ times in length of head.	Diameter of eyes $3\frac{1}{2}-3\frac{2}{3}$ times in length of head.	Diameter of eyes $3\frac{1}{2}$ times in length of head.
Eyes $1-1\frac{1}{2}$ diameters from end of snout and two diameters apart.	Eyes 1 diameter from end of snout and $1-1\frac{1}{2}$ diameters apart.	Eyes 1 diameter from end of snout and $1\frac{1}{2}-1\frac{2}{3}$ diameters apart.
Rostral barbels about as long as the orbit.	Rostral barbels not so long as the eye.	Rostral barbel a little less than $1\frac{1}{2}$ times the orbit.
Maxillary barbels sometimes equalling $1\frac{1}{2}$ diameters of the orbit.	Maxillary barbels as long as the orbit.	Maxillary barbels are only half longer than the orbit.
Dorsal fin commences slightly opposite to the insertion of the ventral.	Dorsal fin commences slightly opposite the insertion of the ventral.	Dorsal commences slightly in advance of the ventral.
Predorsal scales 10-11.	Predorsal scales 12.	Predorsal scales 10.

The only characters that would help to distinguish the three species from the descriptions of Günther (1861) are the following:

<i>B. sarana</i> (Ham.)	<i>B. chrysopoma</i> Cuv. & Val.	<i>B. pinnauratus</i> Day
Ll. 31 Ltr. 5½/6	Ll. 29 Ltr. 6/5	Ll. 29 Ltr. 5/4½
Barbels of moderate length, about as long as the eye.	Barbels small, not longer than the eye.	Barbels small, scarcely as long as the eye.

He also remarked (Günther, *op. cit.*, p. 116) that *B. caudimarginatus* Blyth was indistinguishable from the specimens of *B. rubripinnis* Cuv. & Val.

Raj (1916) found examples of *Barbus* possessing the characters of the three species, *B. sarana* (Ham.), *B. chrysopoma* Cuv. & Val. and *B. pinnauratus* Day, and doubted whether they formed distinct species. Hora and Misra (1942) 'after an examination of large series of specimens of these three species' stated that they are synonymous. They however mentioned that the specimens occurring in Northern India possess more scales along the Ll. (32-34) and in front of the dorsal fin (12) than those found in South India and Burma (Ll. 28-32, Predorsal 10-12).

Blyth (1860) described the species, *B. caudimarginatus* from Tenasserim province. He gave the distinguishing characters of the species as 'barbules well developed, the principal dorsal spine robust and passing into a soft ray for its terminal fourth, being finely pectinated behind and preceded by three distinct spines, the first very minute; Ll. 32; Ltr. 10, D. 4/8; and vertical diameter of the eye fully half that of head.' Boulenger (1883) described the species *B. oatesii* from the South Shan States. As judged from Boulenger's description, the chief characters that distinguish it from *B. sarana* (Ham.) is its longer head (4-4½ times in total length) the rostral barbel which is shorter than the eye, the number of rays in the dorsal fin (4/8) and Ll. scales (29-33). Annandale (1918) compared a co-type of this species from Fort Stedman and a series of specimens from the Inle Lake and He-Ho basin with *B. caudimarginatus* Blyth and stated that they do not differ in any respect from specimens in the Indian Museum obtained from Tenasserim and Upper Burma and identified by Day and others as *B. sarana* (Ham.). He considered that 'this form is no more than a Burmese race of the common Indian *B. sarana* (Ham.), differing only in colouration and in more variable number of lateral line scales. Vinciguerra (1889) discussed the wide variations of characters shown by *B. sarana* (Ham.) and pointed out its close relationship with *B. caudimarginatus* Blyth, *B. pinnauratus* Day, *B. chrysopoma* Cuv. & Val. and *B. rubripinnis* Cuv. & Val. However, Hora (1921), who consulted the same sources examined by Annandale (*op. cit.*), was convinced after a careful examination of the large series of specimens, that *B. oatesii* Boulenger is a distinct species and that Annandale's own specimens undoubtedly belong to the true *B. caudimarginatus* Blyth. He distinguished *B. oatesii* Boulenger from *B. caudimarginatus* Blyth as follows:

<i>B. oatesii</i> Blgr.	<i>B. caudimarginatus</i> Blyth
Dorsal spine strongly serrated, 12 to 19 serrations on each margin of its posterior border.	Dorsal spine finely serrated only in its upper half or 2/3, number of serrations indefinite.
Each scale edged with black.	....
Caudal fin is long and deeply notched, the lower lobe being broader and longer.	Caudal relatively shorter in length and is not so deeply notched, lobes are equal in length.

Prashad and Mukerji (1929) agreed with Annandale (*op. cit.*) that *B. caudimarginatus* Blyth is only a Burmese race of *B. sarana* (Ham.) differing in the number of Ll. scales.

*Prashad and Mukerji (*op. cit.*) described two new species, *B. sewelli* and *B. myitkyinae* from Indawgyi Lake, Upper Burma. A comparison of the data given in

their descriptions with the description of *B. sarana* in Day (1889) shows that they distinguished the species from *B. sarana* (Ham.) by the following characters:—

<i>B. sarana</i> (Ham.)	<i>B. sewelli</i> P. & M.	<i>B. myitkyinae</i> P. & M.
Ll. 32-34, Ltr. $5\frac{1}{2}$ -6/6	Ll. 32-36, Ltr. 10 ($5\frac{1}{2}$ - $4\frac{1}{2}$)	Ll. 32-34, Ltr. 9 ($5\frac{1}{2}$ - $3\frac{1}{2}$)
Diameter of eye $4\frac{1}{2}$ - $4\frac{3}{4}$ in length of head.	Diameter of eye 3.4-3.8 in length of head.	Eye 3.2-3.8 in length of head.
Predorsal scales 10-11.	Predorsal scales 10 or 11.	Predorsal scales 11 or 12.
Maxillary barbels longer than orbit, sometimes $1\frac{1}{2}$ diameters of the orbit.	Maxillary barbels almost equal to or slightly longer than the diameter of the eye.	

Hora and Mukerji (1934), however, after an examination of the material in the Indian Museum stated that *B. sewelli* P. & M. should be regarded as only a local race of *B. sarana* (Ham.) distinguished from it and from *B. caudimarginatus* Blyth by its 'gorgeous colouration,' proportionately longer head, bigger eyes and somewhat narrower caudal peduncle.

Hora (1937a) described a new species, *Barbus binduchitra* from Sando-way, Lower Burma. From a comparison of his description of the species with Day's *B. sarana* (Ham.), it will be seen that he distinguished it from the latter by the following characters:

<i>B. binduchitra</i> Hora	<i>B. sarana</i> (Ham.)
P. 16 V. 10	P. 16 V. 9
Ll. 28-30	Ll. 32-34
Ltr. $5\frac{1}{2}$ / $4\frac{1}{2}$	Ltr. $5\frac{1}{2}$ -6/6
Head 4.5-4.7 times in total length.	Head 5 to $5\frac{1}{2}$ in total length.
Diameter of eyes $4\frac{1}{2}$ - $4\frac{3}{4}$ in head.	Diameter of eyes 2.6-3.5 in head.
Broad vertical band below the commencement of the dorsal fins which extends to the lateral line.	Vertical band absent.

He remarked that *B. binduchitra* Hora shows considerable affinity with *B. pinnauratus* Day from South India and with *B. sewelli* Prashad and Mukerji from Myitkyinae District. He was able to distinguish *B. sewelli* by its deeper body (2.3 to 2.5 times in total length) and the absence of the vertical band and the caudal spot characteristic of *B. binduchitra* Hora. *B. pinnauratus* (Day) was considered a separate species on account of its proportionately longer and less high head, relatively smaller eye, lesser interorbital width, and the relatively more compressed and less high body. The sub-dorsal band though smaller and less prominent has been noted in specimens of *B. pinnauratus* Day by Hora (1937 b) and Das (1937). Hora (1937 a, p. 336) added the names of *B. caudimarginatus* Blyth, *B. oatesii* Boulenger, *B. sewelli* Prashad and Mukerji, *B. myitkyinae* Prashad and Mukerji and *B. binduchitra* Hora to the complex of allied species of *B. chrysopoma* Cuv. & Val., *B. pinnauratus* Day and *B. sarana* (Ham.) already referred to by Raj (1916). Hora and Nair (1941) stated that *B. pinnauratus* Day and *B. chrysopoma* Cuv. & Val. can be distinguished by the difference in the number of predorsal scales. However, they remarked that the three species, *B. sarana*, *B. chrysopoma*, and *B. pinnauratus* along with *B. caudimarginatus* Blyth and *B. sewelli* Prashad and Mukerji 'form a series of very closely allied species the specific limits of which are by no means well defined'. A close scrutiny of the descriptions and notes relating to these species

failed to provide dependable characters for the identification of these species. The only form of a satisfactory key that could be drawn up from these characters is as follows:—

1.	Height of body not more than 3 times in total length	..	..	..	2
	Height of body more than 3 times in total length	..	..	..	4
2.	Height of body not more than 2.5 times in total length	..	..	<i>B. sewelli</i> P. & M.	3
	Height of body more than 2.5 times in total length	..	..	..	3
3.	Length of head not more than $4\frac{1}{2}$ in total length	..	..	<i>B. oatesii</i> Blgr.	
	Length of head more than $4\frac{1}{2}$ in total length	..	..	<i>B. mythyinae</i> P. & M.	
4.	Diameter of eye 2 times in length of head	..	..	<i>B. caudimarginatus</i> Blyth.	
	Diameter of eye more than 2 times in length of head	..	..	..	5
5.	Diameter of eye more than 4 times in length of head	..	..	<i>B. sarana</i> (Ham.)	
	Diameter of eye less than 4 times in length of head	..	..	..	6
6.	A dark blotch behind the gill opening present	..	..	..	7
	A dark blotch behind the gill opening absent	..	..	<i>B. binduchitra</i> Hora.	
7.	Predorsal scales 12 (A. 8)	..	..	<i>B. chrysopoma</i> C.V.	
	Predorsal scales 10 (A. 7)	..	..	<i>B. pinnauratus</i> Day.	

That this key is not tenable and does not serve to distinguish them as different species will be evident from the morphometric data given below.

MORPHOMETRIC DATA.

The morphometry of 53 specimens of *B. sarana* (Ham.), 9 specimens of *B. chrysopoma* C.V., 39 specimens of *B. caudimarginatus* Blyth, 21 specimens of *B. mythyinae* P. & M., 11 specimens of *B. binduchitra* Hora, 19 specimens of *B. pinnauratus* Day, 4 specimens of *B. oatesii* Boulenger and 2 specimens of *B. sewelli* P. & M. were studied and the ranges of morphometric characters are presented in Table I. This shows that the characters of each of the species are almost completely overlapped by the characters of *B. sarana* (Ham.) samples. The colouration and the serrations of the dorsal spine have been found to be highly variable within populations and cannot at any rate be employed in separating them into species. In this connection the observation of Mookerjee *et al.* (1943), that a linear band is present on the back below the insertion of the dorsal fin in the young of *B. sarana* (Ham.) which gradually gets rounded and disappears in the adult, is of interest.

BIOMETRIC COMPARISON.

The various measurements of the samples studied are plotted against the total length of individuals in Text-figs. 1-5. These diagrams demonstrate how closely the particular values for different species crowd together along the curve.

For a correct estimate of the taxonomic position of each of the samples the range, mean, standard deviation, and standard error, were calculated for six characters considered dependable. Text-figs. 6 to 8 present this data in graphic form. For each sample the diagram shows (1) the total range of variation of the particular character by a vertical line; (2) by the solid long rectangle, one standard deviation on each side of the mean; (3) by the hollow broader rectangle, twice the standard error on each side of the mean; and (4) the mean which is marked by the cross-bar. From the overlap of the rectangles delineating the standard error it will be clear that the differences between the samples are not significant except for *B. pinnauratus* Day in the length of head, height of body and number of predorsal scales and for *B. binduchitra* Hora in the number of Ll. scales and predorsal scales and the height of body. As already mentioned, the data of the small samples of *B. sewelli* P. & M. and *B. oatesii* Boulenger were compared with samples proved to be identical with *B. sarana* (Ham.) following the method recommended by Simpson and Roe (*op. cit.*). The results are given in Tables II and III.

TABLE II.
Biometrical data for *B. oatesii* Blgr.

Character	Range	Mean	Standard deviation	Standard error	Standard error of the difference between means	<i>t</i>	<i>P</i>
TL/Hd ..	4.83-4.91	4.87	.057	.040	0.026	1.00	greater than 0.10
TL/Ht ..	4.1-4.9	4.49	.579	.409	1.486	0.64	do.
Hd/Length of Rostral Barbel	4.0-5.5	4.45	.507	.254	0.423	0.57	do.
Hd/Length of maxillary Barbel	4.0-5.5	4.45	.354	.177	1.593	1.01	do.
Ll. ..	29-33	31.50	1.756	.878	0.892	0.42	do.
Predorsal ..	11-12	11.25	0.500	.250	0.087	1.00	do.

TABLE III.
Biometrical data for *B. sewelli* P. & M.

Character	Range	Mean	Standard deviation.	Standard error.	Standard error of the difference between the means	<i>t</i>	<i>P</i>
Hd/Length of Rostral Barbel	3.67-3.75	3.71	.056	.040	.591	1.6	0.10
Hd/Length of maxillary Barbel	2.44-3.00	2.72	.396	.279	.414	1.8	greater than 0.05
Ll. scales ..	31-32	31.5	.700	.500	1.220	0.4	greater than 0.10
Predorsal scales	11-12	11.5	.700	.500	.17	1.0	0.10

In the case of *B. sewelli* P. & M. two characters, viz. TL/Hd and TL/Ht were not statistically tested since only a single value was available in each case. Even though Simpson and Roe (*op. cit.*, p. 212-221) gives a method for statistical tests of single observations, it was found unnecessary to adopt it in the present case as the observed values fell well within the range of values for *B. sarana* (Ham.). From Tables II and III it will be clear that the samples of *B. sewelli* P. & M. and *B. oatesii* Blgr. are statistically the same as *B. sarana*.

Text-figures 6a, 6b and 7a showed significant differences for the values of *B. binduchitra* Hora and *B. pinnauratus* Day. The degree of intergradation of the significant characters of each sample was therefore determined employing Ginsburg's (*op. cit.*) method. Table IV gives the frequency distribution of the number of predorsal scales of *B. binduchitra*, *B. pinnauratus* and *B. sarana*, expressed as percentages of the total number of specimens of each species examined.

TABLE IV.

Species	Predorsal scales					
	8	9	10	11	12	13
<i>B. sarana</i> .. ..	..	2.1	19.2	29.8	38.3	10.6
<i>B. binduchitra</i> .. ..	..	28.6	57.1	14.8	..	..
<i>B. pinnauratus</i>	5.3	26.3	36.8	15.8	15.8	..

It will be seen from the above Table that *B. binduchitra* intergrades with *B. sarana* to the extent of about 18% and the divergence is nearly 82%. *B. pinnauratus* intergrades with *B. sarana* to the extent of about 27%, the divergence being 73%. Table V gives the frequency distribution of the number of Ll. scales of *B. sarana* and *B. binduchitra* expressed as in Table IV.

TABLE V.

Species	Ll. scales							
	28	29	30	31	32	33	34	
<i>B. sarana</i> ..	4.0	8.0	12.0	32.0	26.0	12.0	6.0	
<i>B. binduchitra</i> ..	43.0	28.5	28.5	..	..	..	..

The above Table shows that *B. binduchitra* intergrades with *B. sarana* to the extent of 12% and the divergence between them is 88%. Table VI gives the frequency distribution of the proportion of height of body in total length of *B. sarana*, *B. binduchitra* and *B. pinnauratus*, expressed as in the previous Table.

TABLE VI.

Species	Total Length/Height of body							
	3.1-3.2	3.3-3.4	3.5-3.6	3.7-3.8	3.9-4.0	4.1-4.2	4.3-4.4	4.5-4.6
<i>B. sarana</i> ..	9.1	36.4	27.3	24.2	..	3.0	..	..
<i>B. binduchitra</i> ..	..	..	9.1	27.3	27.3	..	27.2	9.1
<i>B. pinnauratus</i> ..	..	5.9	23.4	29.3	..	..	..	..

The intergradation between *B. sarana* and *B. binduchitra* as can be seen from the above Table is about 18% and the divergence, 82%. *B. pinnauratus* intergrades to the extent of 27% with *B. sarana* and the divergence is 73%.

Thus in respect of these three characters *B. binduchitra* intergrades with *B. sarana* more than 10% and less than 25%, qualifying for the rank of a sub-species

as proposed by Ginsburg (*op. cit.*). In the case of *B. pinnauratus* it has been seen that it intergrades with *B. sarana* to the extent of 27% in the number of predorsal scales and the height of body, and as such can be considered a race. That *B. pinnauratus* and *B. binduchitra* are separate will be evident from the diagrams showing the biometric data for Tl/Hd, Hd/d and Ll. scales.

While *B. sarana binduchitra* forms a geographic sub-species recorded only from Sandoway, Lower Burma, *B. sarana* race *pinnauratus* is more widely distributed. Day (1889) describes its habitat as 'from fresh waters at Coconadda own the East Coast of India to Ceylon, and inland as far as the Nilgiris, also along the Western Ghats and rivers at their bases'. It has since been recorded from Bihar (Das, 1937) and identified from Malaya by Mr. A. G. K. Menon of the Zoological Survey of India Laboratories (Private communication).

SYNONYMY.

The synonyms of *Barbus sarana* (Ham.) are the following:—

Barbus sarana (Ham.)

<i>Cyprinus kunnamoo</i>	..	Russell. <i>Fish. Vizag.</i> , 2, 1803, 82.
„ <i>kakoo</i>	..	Russell. <i>Fish. Vizag.</i> , 2, 1803, 83.
„ <i>kadoon</i>	..	Russell. <i>Fish. Vizag.</i> , 2, 1803, 83.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60.
„ <i>sarana</i>	..	Hamilton Buchanan. <i>Fish. Ganges</i> , 1822, 307, 388.
<i>Systomus immaculatus</i>	..	McClelland. <i>Asiat. Res.</i> , 19, 1839, 284, 380-381.
„ „	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 409.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 62.
<i>Systomus chrysosomus</i>	..	McClelland. <i>Asiat. Res.</i> , 19, 1839, 284.
„ „	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 409.
<i>Systomus chrysopoma</i>	..	Jerdon. <i>Madr. Journ. Lit. Sci.</i> , 1849, 314.
<i>Barbus deliciosus</i>	..	McClelland. <i>Asiat. Res.</i> , 19, 1839, 272, 342.
„ „	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 15, 1842, 172.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60.
<i>Barbus gardonoides</i>	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 156.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60, 126.
<i>Barbus kakus</i>	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 153.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60.
<i>Barbus duvaucelli</i>	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 167.
<i>Barbus immaculatus</i>	..	Günther. <i>Catal. Acanth. Fish. Brit. Mus.</i> , 7, 1861, 121.
<i>Barbus rusellii</i>	..	Günther. <i>Catal. Acanth. Fish. Brit. Mus.</i> , 7, 1861, 121.
<i>Barbus polyodori</i>	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 165.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60.
<i>Barbus chrysopoma</i>	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 165.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60.
„ „	..	Day. <i>Fish. Mal.</i> , 1865, 208.
„ „	..	Günther. <i>Catal. Acanth. Fish. Brit. Mus.</i> , 7, 1861, 113.
<i>Barbus caudimarginatus</i>	..	Blyth. <i>J. Asiat. Soc. Bengal.</i> , 23, 1860, 156.
<i>Barbus sarana</i>	..	Cuvier and Valenciennes. <i>Hist. Nat. Poiss.</i> , 16, 1842, 151.
„ „	..	Bleeker. <i>Verh. Bat. Genoo.</i> , 25, 1853, 60.
„ „	..	Jerdon. <i>Madr. Journ. Lit. Sci.</i> , 15, 1849, 312.
„ „	..	Günther. <i>Catal. Acanth. Fish. Brit. Mus.</i> , 7, 1861, 115.
<i>Puntius sarana</i>	..	Steindachner. <i>Sitz. A.K. Wiss. Wien</i> , 61, 1867, 58.
<i>Puntius chrysopoma</i>	..	Day. <i>Fish. Mal.</i> , 1865, 208.

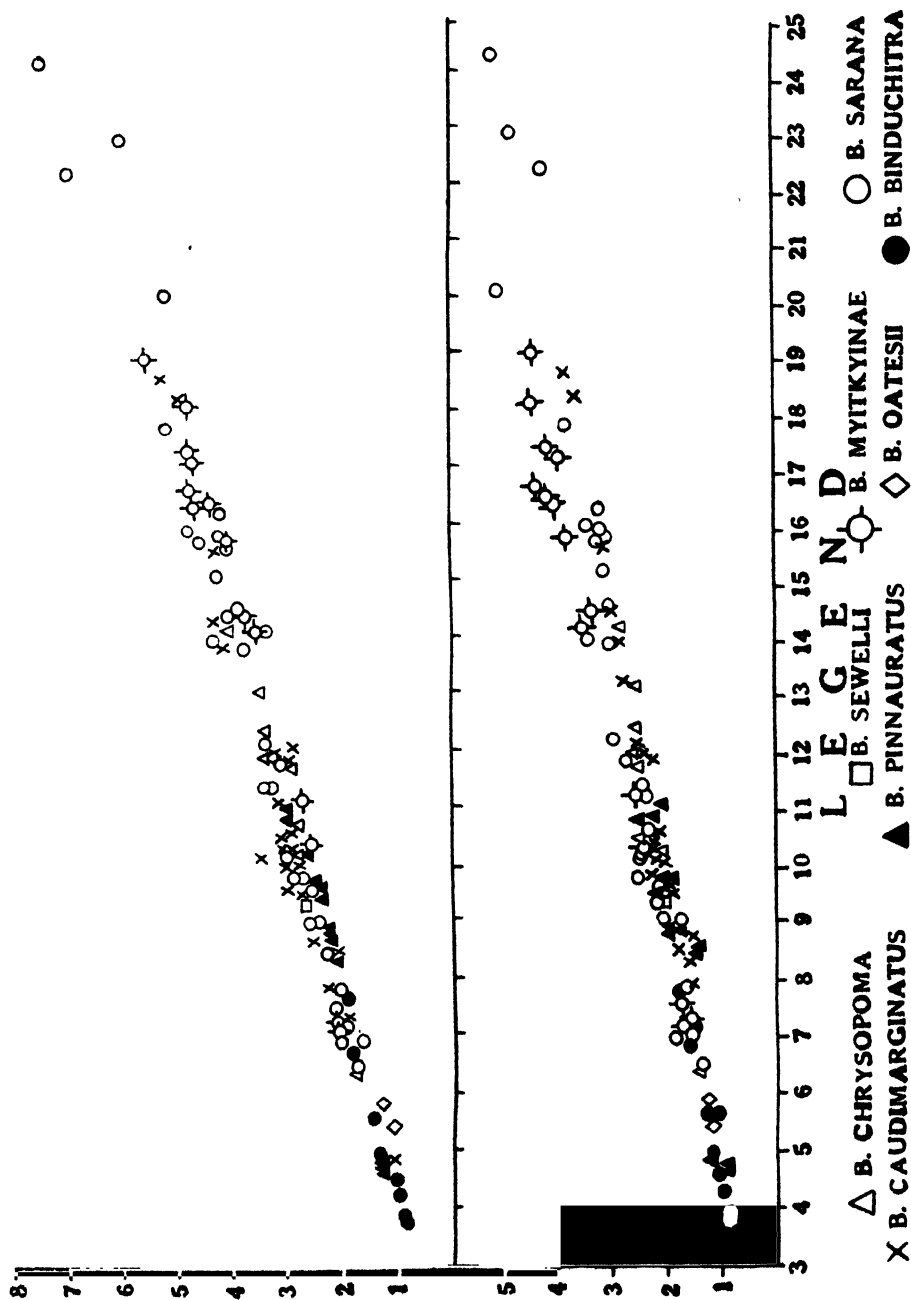
Though it has not been possible to examine material relating to the above species and *B. rubripinnis* Cuv. & Val. the morphometric table indicates that they are only synonyms of *B. sarana* (Ham.) Synonyms of *B. sarana* race *pinnauratus* have already been considered in the review of the literature.

SUMMARY.

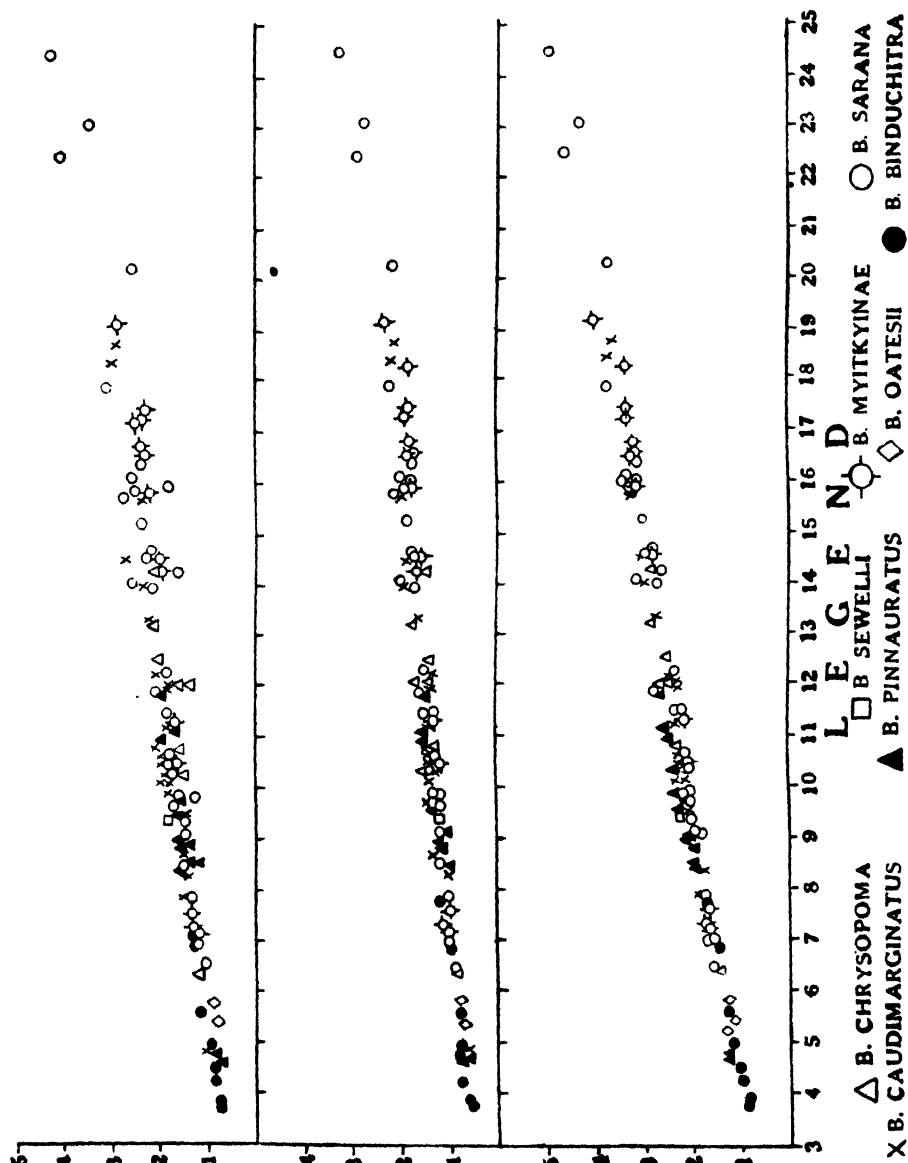
The literature relating to the systematics of *B. sarana*, *B. chrysopoma*, *B. pinnauratus*, *B. caudimarginatus*, *B. oatesii*, *B. myitkyinae*, *B. sewelli*, and *B. binduchitra* is reviewed and from the descriptions of previous workers a key for the species is drawn up. The morphometry of the samples of these species in the collections of the Zoological Survey of India is presented and it is shown that this key is not tenable and the characters of *B. sarana* almost completely overlaps the characters of the other species. The morphometric data is biometrically analysed and the results show that *B. binduchitra* can be considered a sub-species of *B. sarana* and *B. pinnauratus* as a race of *B. sarana*. The other species are synonymous with *B. sarana*.

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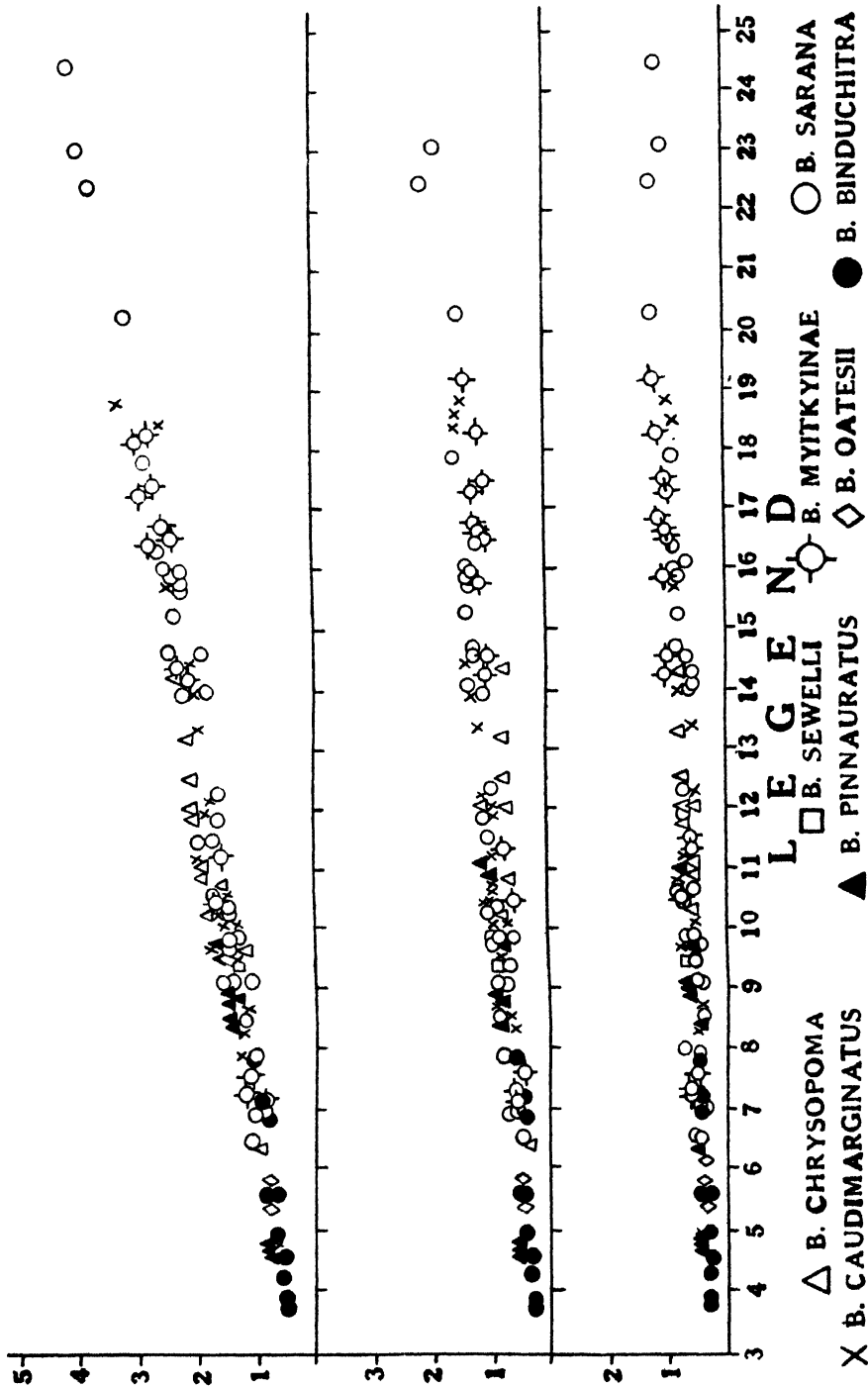
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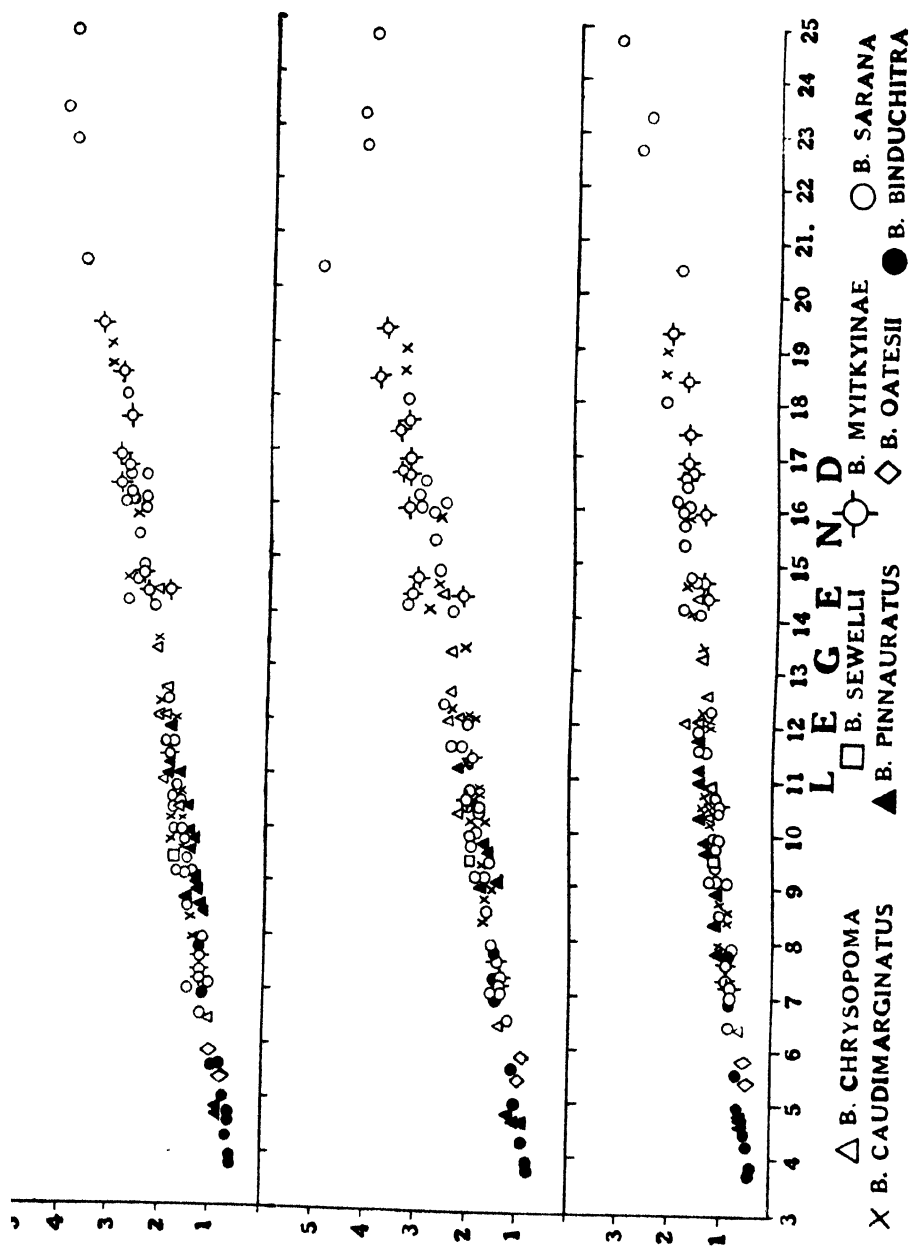
TEXT-FIG. 1. Scatter diagrams showing (from below upwards), (1) the caudal length and (2) the depth of body, plotted against the total lengths of specimens (in cm.) of each species.



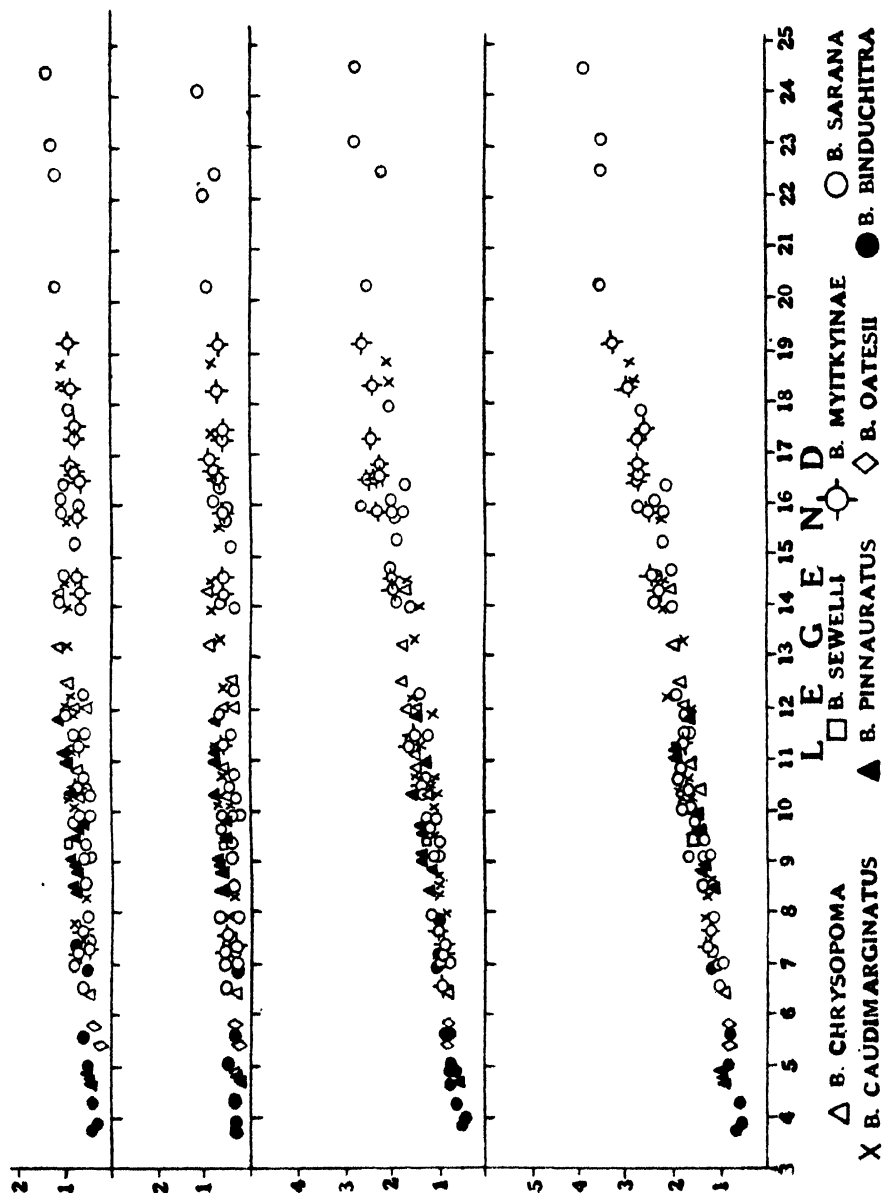
TEXT-FIG. 2. Scatter diagrams showing (from below upwards), (1) the length of head, (2) width of head, and (3) height of head, plotted against the total lengths of specimens (in cm.) of each species.



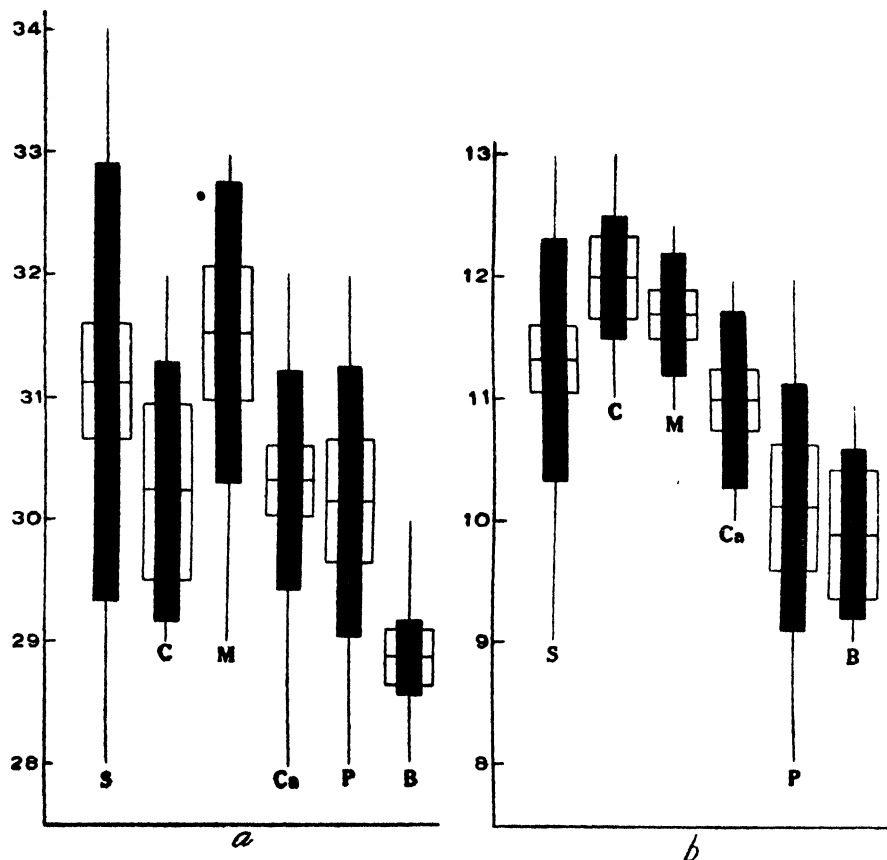
TEXT-FIG. 3. Scatter diagrams showing (from below upwards), (1) the diameter of eyes, (2) inter orbital distance, and (3) length of caudal peduncle, plotted against the total lengths of specimens (in cm.) of each species.



TEXT-FIG. 4. Scatter diagrams showing (from below upwards), (1) the least height of caudal peduncle, (2) length of the longest ray of the dorsal fin, and (3) length of the pectoral fin, plotted against the total lengths of specimens (in cm.) of each species.



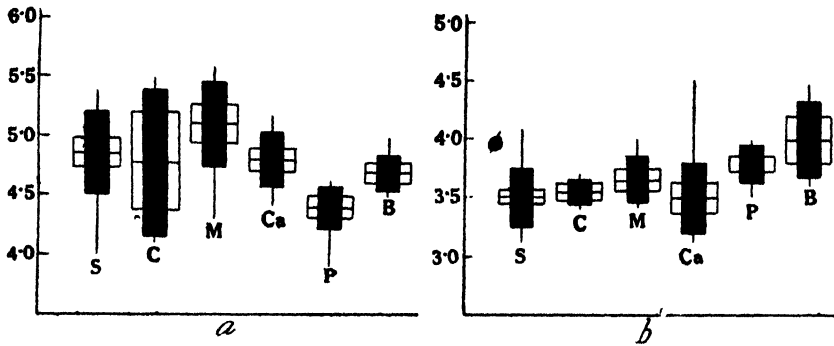
TEXT-FIG. 5. Scatter diagrams showing (from below upwards), (1) the length of ventral fin, (2) length of longest ray of anal fin, (3) length of rostral barbel, and (4) length of maxillary barbel, plotted against the total lengths of specimens (in cm.) of each species.



TEXT-FIG. 6. *a*—Graph showing the variation in the number of lateral line scales in the samples of each species.

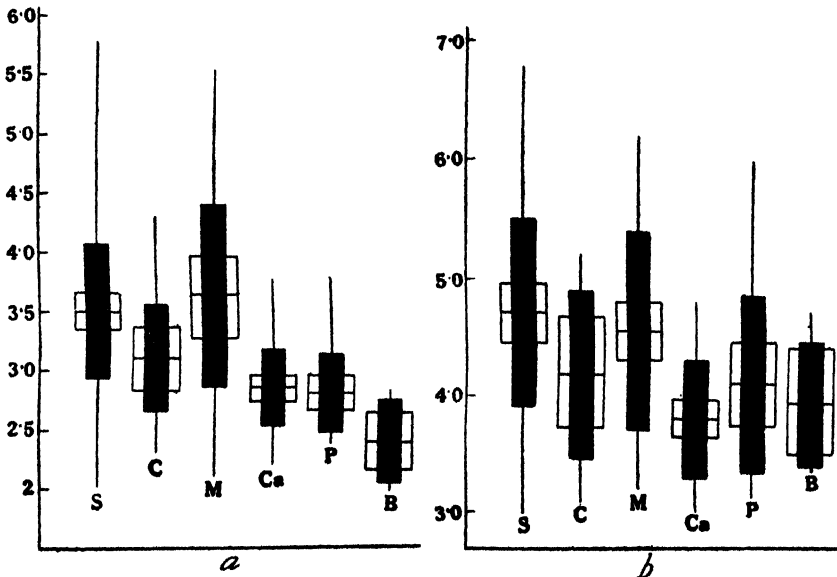
b—Graph showing the variation in the number of predorsal scales in the samples of each species.

S—*Barbus sarana*, C—*B. chrysopoma*, M—*B. myitkyinae*, Ca—*B. caudimarginatus*, P—*B. pinnauratus*, B—*B. binduchitra*. (The same lettering is used in Text-figs. 7 and 8.)



TEXT-FIG. 7. *a*—Graph showing the variation in the length of head in the samples of each species.

b—Graph showing the variation in the height of body in the samples of each species.



TEXT-FIG. 8. *a*—Graph showing the variation in the length of the maxillary barbel in the samples of each species.

b—Graph showing the variation in the length of the rostral barbel in the samples of each species.

NEAR ULTRAVIOLET ABSORPTION OF ORTHO-CHLORO-PHENOL VAPOUR.

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A new impetus has been given to the study of the electronic band systems of poly-atomic molecules by the successful solution of the vibrational classification of the well-known near ultraviolet bands of benzene. Experimental investigations on Benzene and its Deutro-derivatives by Ingold and his collaborators (1936), and the theoretical calculation of the energy of electronic excitation in the highly symmetrical structure of the benzene molecule by M. Goeppert-Mayer and Sklar (1938), led to the complete correlation of the spectra of heavy and ordinary benzenes in solid, liquid and vaporous states by Sponer, Nordheim, Sklar and Teller (1939). As a logical extension, the study of the monosubstituted benzenes was taken up by a number of workers, Sponer and Teller (1941), Sponer and Wollman (1941), Wollman (1946), Matsen, Ginsberg and Robertson (1945) Ginsberg and Matsen (1945), Ginsberg, Robertson and Matsen (1946), Hirt and Hower (1948), Asundi and Padhye (1949), Padhye (1949), Sreeramamurty and K. R. Rao (1949) and Sreeramamurty (1949 and 1950). These investigations are important in that they give us the vibrational frequencies of both the normal and excited electronic states of the molecules concerned. Raman and infra-red studies, though they relate to the normal state only, are also of immense value in the interpretation of the vibrational structure of the ultra-violet absorption bands. The author has taken up for study a di-substituted benzene molecule, ortho-chloro-phenol, and the results are given in this paper.

The general experimental set up is that employed in an earlier investigation on CS₂ molecule (Ramasastry and K. R. Rao, 1947). The absorbing gas has been maintained at various conditions of pressure and path length but always at the room temperature. The pressure in the absorption tube was altered by keeping the liquid container in ice and freezing mixtures in a thermos flask. Path lengths ranged from 5 cms. to 100 cms. and the container temperatures from -16°C. to 40°C. Hilger Medium Quartz Spectrograph having a dispersion of about 7.5 Å./mm. at 2700 Å. was employed as the dispersing instrument. The Iodine source (Ramasastry, 1947) supplied the continuous background. Times of exposures varied from 15 minutes to two hours on Ilford Special rapid plates.

RESULTS.

Pictures showing the absorption of the vapour of Ortho-Chloro-Phenol at various effective path lengths are presented in Plate VIII. The bands altered in appearance as the path length and/or pressure is varied. With increase of these factors, the strong bands grew stronger and also broadened while new ones made their appearance. The wavelengths of the bands given in Table I correspond to the measurements made when they are narrowest and sharpest; usually the wavelength of a band is adopted from measurements of the spectrogram in which it made its first appearance, i.e. just visible. The intensity classification is made on the basis that the bands appearing with the lowest effective path length are to be considered as strongest. The data are selected from various spectrograms and collected

in Table I. The appearance of the bands shows that no high accuracy can be expected in their measurements and as such can only be claimed to be correct to two to three wave numbers in favourable cases.

INTERPRETATION.

The molecule Ortho-Chloro-Phenol, $\text{Cl.C}_6\text{H}_4\text{OH}$, has got only one element of symmetry, namely the plane of the molecule (σ_h), if it is assumed that the chlorine and hydroxyl substitutes also lie in the plane of the ring. The molecule then belongs to the Point Group $\text{C}_s \equiv \text{C}_{1h}$. Of the $3N-6 = 33$ non-degenerate fundamental vibrations that the molecule should have, some will be symmetrical and others antisymmetrical to this symmetry operation of reflection in the molecular plane.

Following Herzberg (1945), the total number of atoms in the molecule is

$$N = 2m + m_0$$

m = No. of sets of equivalent nuclei not on any element of symmetry.

m_0 = No. of nuclei lying on all symmetry elements present.

No. of A' vibrations (symmetrical) $3m + 2m_0 - 3 = 0 + 26 - 3 = 23$

No. of A'' vibrations (anti-symmetrical) $3m + m_0 - 3 = 0 + 13 - 3 = 10$

Total .. 33

The replacement of two of the hydrogen atoms of benzene by a chlorine atom and hydroxyl radical in ortho-chloro-phenol reduces the high symmetry, D_{6h} , of benzene to that of C_s . In certain other disubstituted benzenes in which both the substituting groups are identical (e.g. ortho-dichloro-benzene) the symmetry is C_{2v} , much higher than C_s . Of course, for para substitution, there exists better symmetry in each case. In view of this lowering of symmetry in the case of Ortho-Chloro-Phenol, the selection rules for the transitions in benzene no longer hold good and the near ultraviolet absorption band system should show the characteristics of an allowed transition. The restrictions on the permissibility of the appearance of certain vibrations become less. Consequently its electronic absorption spectrum should be expected to show a complicated appearance.

Nevertheless, an extensive experimental study of the absorption of the vapour of this molecule under various conditions of pressure and path length has made it

TABLE I.
Absorption Bands of Ortho-Chloro-Phenol.

Purvis and McClelland (1913).		Author.		Wave- number.	Distance from 0-0.	Assignment.
Wavelength.	Int.	Wave- length.	Int.			
2870	vw	..	..	34833	-1059	0-1059
2853	w	2851.8	vw	35055	-837	0-837
2840	w	2839.5	vw	35207	-685	0-685
		2834.0	w	35275	-617	0-414-2 × 102
2830		2830.0	w	35325	-567	0-567
		2826.0	w	35276	-516	0-414-102
		2823.3	w	35409	-483	0-483
		2819.7	w	35455	-438	0-4 × 109
		2817.8	w	35478	-414	0-414
		2816.5	w	35495	-397	0-292-105
2809	fs	2810.8	2	35567	-325	0-3 × 108
		2808.2	w	35600	-292	0-292
2807	vw	2805.4	1	35635	-257	0-257
		2801.9	4	35680	-212	0-2 × 106
2804		2799.2	2	35714	-178	0-178
						0-104-64

Purvis and McClelland (1913).		Author.		Wave- number.	Distance from 0-0.	Assignment.
Wavelength.	Int.	Wave- Length.	Int.			
2775	strong absorption	2796.8	2	35745	-147	..
		2793.8	6	35783	-109	0-109
		2790.3	1	35828	-64	0-64
		2785.3	vs	35892	0	0-0
		2776.0	5	36102	120	0+120
2767	vw	2770.7	1	36081	189	0+189
		2766.9	1	36131	239	0+2×120
2763	vw	2761.6	2.5	36200	308	0+495-257
2760	vw	2759.0	1	36234	342	0+120+189
2755	vw	2755	1	36286	394	0+342
2752	vw	2749.9	2.5	36354	462	0+120+342
		2747.4	3	36387	495	0+495
2735	vw	2742.0	3	36459	567	0+3×189
		2736.9	4b	36527	635	0+635
2734		2732.6	3	36584	692	0+2×346
						0+953-257
		2729.1	w	36631	739	0+3×189
		2726.8	3	36662	770	0+953-178
		2724.5	7	36693	801	0+801
		2721.2	4	36738	846	0+953-107
		2718.1	2	36780	888	0+953-65
		2713.3	9	36845	953	0+953
		2703.2	3.5	36982	1090	0+1090
		2700.3	vw	37022	1130	0+495+635
						0+1200-70
		2696.8	2	37070	1178	0+2×495+189
		2695.2	2	37092	1200	0+1200
		2691.3	1	37146	1254	0+1200+120-66
		2685.5	w	37226	1334	0+1445-109
		2677.5	2	37337	1445	0+1445
		2668.8	3	37459	1567	0+1445+120
	w. diff.	2666.0	w	37498	1606	0+2×801
		2663.8	w	37529	1637	0+801+953-109
		2661.4	w	37577	1685	0+801+953-65
		2656.0	4	37639	1747	0+801+953
		2653.7	vw	37672	1780	0+342+635+801
		2645.5	4	37789	1897	0+953+944 or
						0+2×949
		2638.5	w	37889	1997	0+801+1200
		2628.3	w	38036	2144	0+953+1200
		2624.7	w	38088	2196	0+801+1445-64
		2620.5	w	38149	2257	0+801+1445
		2611.5	..	38215	2323	0+2×949+495-65
			w	38281	2389	0+2×949+495
						0+1200+1190 or
						0+2×1195
2608		2607.8	w	38335	2443	0+2512-65
2604		2603.1	w	38404	2512	0+2512 or
						0+2619-107
2601		2600	vw	38450	2558	0+2619-64
2593		2696	vw	38511	2619	0+2619
		2590.8	w	38587	2695	0+2×947+801
2581		2583.6	w	38694	2802	..
		2581.0	vw	38733	2841	0+953+944+944 or
2578						0+3×947
		2574.7	..	38778	2886	0+2×1445
2571		2570	vw	38828	2936	0+801+940+1195
		2556	vw	38899	3007	0+2×1445-120
			vw	39112	3220	0+944+1081+1195
		2550	vw	29204	3312	0+945+2×1195

possible to pick out some of the fundamental vibrational frequencies of the upper and lower states of the molecule; in terms of these the rest of the bands are sought to be analysed.

In the absence of regular rigorous rules for the transition probabilities from different vibrational levels of the ground electronic state to different stages of vibrational excitation in the first excited electronic level of the molecule, the interpretation of the bands occurring on the lower energy side of the 0—0 transition can be only qualitative. However, one guiding principle is that the intensities of these bands are governed to some extent or other by the Boltzman factors which, generally stated, means that the intensities of bands arising from vibrating ground state are smaller the larger the energy of vibration in the ground state, other factors remaining the same. The following considerations are, therefore, subject to the limitations of our knowledge of the selection rules and the weightage factors regarding these transitions.

At the lowest effective path length used, namely 5 cms. absorption tube with the liquid container at -15°C. , Plate VIII (*a*), about four bands appear with measurable prominence. The strongest one at $\lambda 2785.3$, $\nu 35892$, is taken as the 0—0 band. That at $\lambda 2713.3$ is of slightly lower intensity. Separated from the (0—0) by 953 cm.^{-1} , this, perhaps, represents one of the carbon vibrations of the upper state. Less intense than these are two more bands on either side of the (0—0). The shorter wavelength one is interpreted as corresponding to an upper state vibration of frequency 120 cm.^{-1} . This vibration whose fundamental appears with such intensity that it is present on all the plates on which the (0—0) and the (0+953) bands are recorded, also occurs in combination with many of the upper state vibrations.

The band on the long wavelength side occurs at 2793.8 A. and is displaced from the (0—0) by 109 units. In Plate VIII, strips (*a*) and (*b*), very prominent among the bands on the long wavelength side of the 2785.3 A. band representing the 0—0 transition, are those at $2793.8(6)$, $2801.9(4)$, $2810.8(2)$, $2819.7(1)$, gradually decreasing in intensity with their distance from the 0—0. They are equispaced at an average interval of 108 cm.^{-1} . As no Raman frequency of this magnitude is as yet reported, one may be inclined to interpret it as a difference frequency arising out of a 1—1 transition. But the very high intensity of these bands suggests that this 108 cm.^{-1} may be an as yet unnoticed ground state vibrational frequency. Consideration of the intensities of the difference frequency 64 cm.^{-1} and other lower state frequencies in this spectrum also support this view.

The band at 2790.3 A. , interpreted in Table I as 0—64 is to be regarded as a difference frequency, in agreement with the similar explanation of bands with shifts of such small magnitudes in the absorption spectra of allied molecules (benzene and substituted benzenes). Further the value of about 60 cm.^{-1} is actually found to be the difference between a ground state vibration and an upper state vibration. From Table II, either 178 — 120 or 257 — 189 can give rise to a difference frequency of this magnitude. Whether both the above transitions are there or not can best be decided only if the spectrum is recorded in higher dispersion and resolving power, because of this accidental coincidence. The difficulty in choosing between the two arises from the fact that bands representing all the above four vibrations, 178 and 257 of the lower state and 120 and 189 of the upper state are present in the absorption spectrum. However, their very presence lends support to regard 64 cm.^{-1} as a difference frequency. A reference to Table II shows that among the known vibrational frequencies of the lower and excited states of this molecule, there exists no difference of the magnitude of 108 to explain it as a difference frequency. One notices from the spectrograms that the (0—108) band is of far greater intensity, the (0— 2×108) is of greater intensity and the (0— 3×108) band is of lower intensity than the (0—64) band. If the Boltzman factors only are considered, this suggests that the 0—64 band arises out of a ground state vibration of higher energy than the vibrations which give rise to 0—108 and 0— 2×108 bands. Even if it is assumed

that the 0—108 band arises as a difference frequency from the lowest observed Raman shift of 168 cm^{-1} , it cannot explain the higher intensity of 0— 2×108 band over that of the 0—64 band because the — 2×108 band arising from $2 \times 168 = 336 \text{ cm}^{-1}$ energy in the ground state should normally be of lower intensity than the —64 band arising from either 178 or 257 vibrations. So one is led to consider that 108 cm^{-1} is a vibrational frequency of the ground electronic state and that the 64 cm^{-1} is probably a difference frequency arising from the 257 vibration of the same electronic state.¹ Also, the —257 band at $\lambda 2805.4$ is though slightly weaker, is of comparable intensity with the —64 difference frequency band. This again is quite convincing because both these bands arise from the same vibrational level (energy 257 cm^{-1}) of the ground electronic state. A few other bands making their appearance at longer path lengths could be correlated with some of the observed Raman shifts and as combinations thereof. Particular mention may be made of the three long wavelength absorption bands at 2840 Å., 2853 Å. and 2870 Å. recorded by Purvis and McClelland (1913) in their investigation on the ortho-chloro-phenol vapour maintained at a temperature of 45°C. in an all quartz tube of 20 cms. length. Their separations from the (0—0) band are 690, 850, and 1060 cm^{-1} respectively, agreeing with the observed Raman lines at 680, 840, and 1030 cm^{-1} . In the present investigation only the first two bands were recorded faintly at 2839.5 Å. and 2851.8 Å. when a 100 cm. absorption column was used. These give 685 and 837 cm^{-1} for the lower state vibrational frequencies in better agreement with the Raman shifts. The 2870 Å. band, though it is not recorded on our plates, is interpreted in Table I as 0—1060 which obviously corresponds to the Raman shift of 1030 cm^{-1} . The various vibrational frequencies of the ground electronic state of the molecule, ortho-chloro-phenol, that could be derived from the ultraviolet absorption spectrum of its vapour are given in Table II.

TABLE II.
Vibrational Frequencies of Ortho-Chloro-Phenol.

Lower state.			Upper state.
Raman Spectrum.		Ultraviolet absorption.	Ultraviolet absorption.
Morris (1931).	Reynolds and Williams (1930).		
168(1)	..	108	..
..	180(7)	178	120
254(1)	..	257	189
..	270(4)	292	..
..	380(3)	..	..
..	420(2)	414	342
..	490(3)	483	..
559(1)	570(2)	567	495
680(1)	680(3)	685	635
..	770(2)	..	..
829(1)	840(5)	837	801
890(1)	..	..	..
..	960(1)	..	..
1022(2)	1030(4)	1059	953
..	1260(3)	..	1090
..	1290(3)	..	1200
1585(1)	1580(2)	..	1445
2138(1)	..	..	2512
3061(1)	3070(3)	..	2619

¹ 2×108 is still less than 257 so that the higher intensity of the 0— 2×108 band over that of 0—64 band is understandable. This will not be the case if 0—64 is taken to arise from the 178 vibration.

But as regards the intensities of the bands occurring on the short wavelength of the 0—0, apart from the lack of definite theoretical conclusions regarding the transition probabilities and such other factors governing the intensities of these bands, even the Maxwell-Boltzman distribution law is not in general of much use except in the case of bands involving vibrating ground state. The Frank-Condon principle is, however, a rough guide. Further, from the analogy of the already analysed absorption spectra of benzene and its derivatives, and their relation to the infra-red and Raman spectra, one expects that the carbon vibrations occurring round about 1000 cm.^{-1} appear with high intensity in the ultraviolet spectrum.

The 953 cm.^{-1} upper state carbon vibration could be traced up to three quanta, the intensity decreasing with the quantum number. It is also found to combine with 801, 1090 and 1200 frequencies but the combination band $953+1445$ could not be located.* In agreement with what has been said earlier as regards the -64 and -108 displacements from the 0—0, the $0+953-64$ band is weaker than $0+953-108$ band.

Four other fundamentals, 120, 635 and 801 appear with high intensity while the 1200 and 1445 cm.^{-1} vibrations are represented by comparatively weaker bands. The 120 vibration is found excited in combination with a few of the upper state frequencies. In particular the combination bands $120+189$ and $120+342$ are of enhanced intensity than the 189 and 342 bands respectively. On the other hand, the 801 cm.^{-1} vibration, which combined with almost all the vibrations of higher energy than 635 cm.^{-1} , gave rise to bands of considerably lower intensity compared to the corresponding fundamentals.

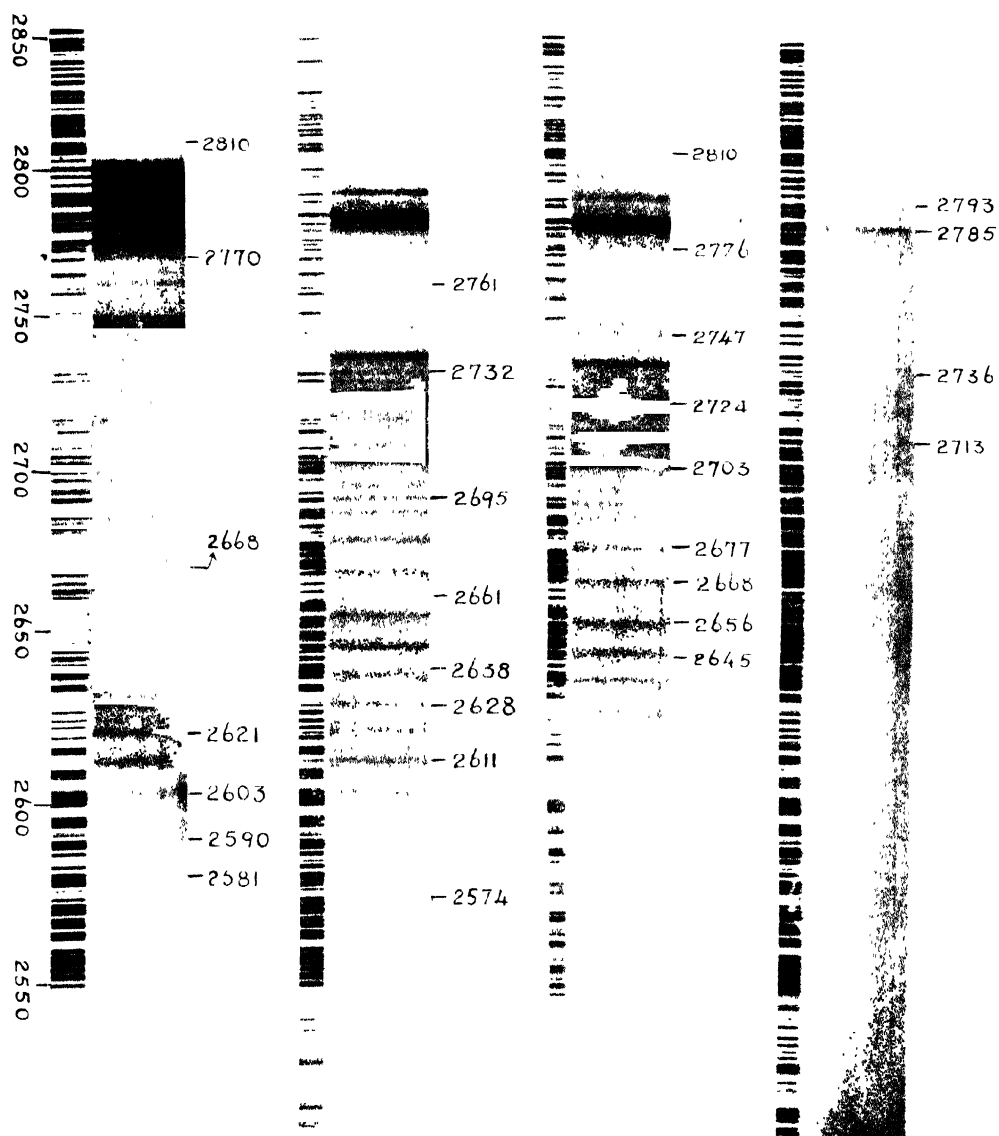
As regards the anharmonicity, the 953 cm.^{-1} vibration is found to decrease in energy slightly when it is excited by more than one quantum or when merely found in combination with other vibrations of about 1000 cm.^{-1} energy. Similar is the behaviour of the 1200 cm.^{-1} vibration. Some of the bands occurring towards the higher energy end of the spectrum had to be explained as combinations of three different vibrations.

Though the bands appear line like at low pressures, they showed a slight degradation when recorded using larger effective path lengths. Red degradation is prominent in the case of the 1090 and 1445 bands and this implies that the excitation of these vibrations in the upper state considerably reduces the moment of inertia of the molecule. Other fundamental bands are probably degraded either way or show a slight degradation towards the red. All the combination bands showed a definite degradation towards longer wavelengths. The 0—0 band, however, is degraded to the violet. This is a unique case in this family of molecules investigated till now, as in the case of almost all the other substituted benzene molecules and benzene the 0—0 band showed a red degradation. In this case, therefore, the mere electronic transition from the lower to the upper state is associated with a slight increase of moment of inertia. However, if a large vibrational energy is superposed on this electronic energy, the moment of inertia decreases and the corresponding bands, as already said, are degraded to longer wavelengths.

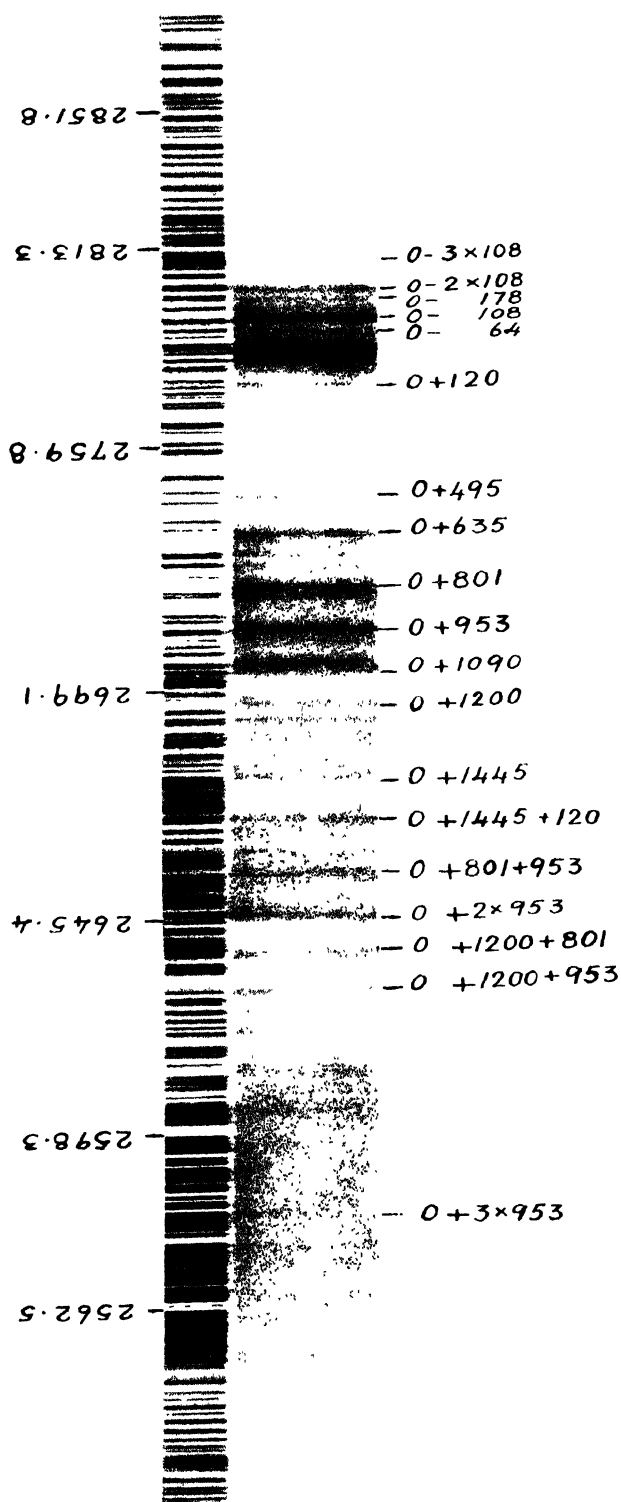
The author is indebted to Prof. Dr. K. Rangadhama Rao for his kind interest in the work and to Dr. D. S. Kothari for his encouragement. He wishes to express his gratefulness to the National Institute of Sciences of India for supporting this research financially by the award of an I.C.I. (India) Research Fellowship to the author.

SUMMARY.

The vibrational classification of the near ultraviolet absorption band spectrum of a disubstituted benzene molecule, Ortho-Chloro-Phenol ($\text{Cl.C}_6\text{H}_4\text{OH}$), consisting of about sixty-five bands between $\lambda\ 2870-\lambda\ 2550$ was carried out. Vibrational frequencies of 108, 178, 257, 292, 414, 483, 567, 685, 837 and 1080 were found to be associated with the ground electronic state, while the frequencies of 120, 189, 342, 495, 635, 801, 953, 1090, 1200, 1445, 2512, and 2619 cm.^{-1} , represented the upper state vibrations. A difference frequency of 64 cm.^{-1} has also been noticed



Absorption Spectrum of Ortho-Chloro-Phenol Vapour.



Absorption spectrum of Orthochloro-Phenol Vapour

and explained as a 1—1 transition involving the 257 and the 189 cm^{-1} vibrations of the two electronic states.

A prominent feature of the spectrum is the violet degradation of the 0—0 band (λ 2785.3, ν 35892) while in the case of most of the allied molecules the band showed a marked degradation to the red.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION— PARTS VII AND VIII.

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PART VII. RESPONSES OF THE ADRENO-CORTICAL ALKALINE PHOSPHATASE IN THE PIGEON TO EXPERIMENTAL HYPERADRENALISM.

INTRODUCTION.

The presence of alkaline phosphatase has been demonstrated cytochemically in the mammalian adrenal cortex and also in that of the pigeon. The distribution of this enzyme in the cortex of the rat (Dempsey *et al.*, 1949) and the mouse (Elftman, 1947) exhibits a marked sexual dimorphism. Much more of the enzyme is present in the male than in the female. Dempsey *et al.* (1949) observed that the phosphatase disappears from the fasciculata and the reticularis of the rat's adrenal cortex after hypophysectomy but persists in the zona glomerulosa. Replacement therapy with whole pituitary powder causes a reappearance of the enzyme and a return to a condition approximating that of the normal gland. Alkaline phosphatase is absent from the adrenal cortex of the castrated male, the ovariectomized female, and the immature male mice (Elftman, 1947). Treatment of such animals with testosterone propionate results in the restoration of the cortical phosphatase activity.

In the pigeon there are considerable amounts of alkaline phosphatase in the adrenal cortical strands located in the central region of the gland but in the peripheral cortical masses there is very little enzyme activity. Treatment with estrogen or androgen reduces cortical phosphatase activity (Kar, 1950a). Progesterone or desoxycorticosterone acetate administrations, however, are associated with a pronounced augmentation of enzyme activity in the cortex of this species (Kar, 1950b).

The present report relates to a study of the effects of experimental hyperadrenalism caused by adrenalin, on the distribution and concentration of alkaline phosphatase in the adrenal cortex of the pigeon. An effort has also been made to test the action of gonadotropic hormone on the adreno-cortical phosphatase activity in the adrenalin-treated birds.

EXPERIMENTAL PROCEDURE.

Male pigeons were used in this study. A total of 15 birds were experimented on, of which 5 were injected with adrenalin, 5 with adrenalin plus gonadotropic hormone, and the remaining 5 were left uninjected to serve as controls. The birds were housed in cages and maintained under uniform husbandry conditions throughout the duration of the experimental period.

Liq. Adrenalin tartratis (Standard Pharmaceutical Works, Calcutta), 1:1,000 dilution, was administered intramuscularly to one group of birds. The daily injection (2 minims = 0.108 c.c.) were made into the pectoral muscles and continued

for a period of 8 days. An equal amount of this drug (2 minims daily) was injected in the similar manner and over the same period of time to a second group of pigeons. In addition to adrenalin this group also received four injections of 'Gestyl' (Organon Laboratories), each containing 100 I.U. of serum gonadotropin. The gonadotropic hormone therapy started simultaneously on the second day of adrenalin treatment and was continued on every alternate days till the 8th day, and 24 hours subsequent to which all the birds were autopsied.

The adrenals were carefully dissected out and fixed immediately in chilled 80 per cent ethyl alcohol. After dehydration and imbedding in paraffin serial sections were prepared, 6 microns in thickness. The technique of Gomori (1941) was used for the demonstration of alkaline phosphatase. The details of this technique have been described in previous communications by the writer (Kar, 1950a and b).

RESULTS.

Controls.—The distribution of alkaline phosphatase in the adrenal cortex of normal pigeons has been described in two previous papers (Kar, 1950a and b). In agreement with our findings, we observed that the capsule of the gland gives a positive reaction for the enzyme. The endothelium of the capsular blood vessels also shows the presence of alkaline phosphatase. In the cells of the peripheral cortical strands the enzyme is present in the nucleus but not in the cytoplasm. A pronounced activity of the phosphatase, however, is observed in the cortical masses of the central region of the gland. Here, the enzymatic reaction uniformly appears in the cytoplasm as well as in the nucleus of the cells of these masses (Pl. X, fig. 1). The endothelium of the stromal capillary network also shows strong phosphatase activity.

Adrenalin treatment.—Alkaline phosphatase is prominently absent from the adrenal capsule of the treated pigeons. However, a slight activity of the enzyme is retained in the endothelium of the capsular blood vessels. The peripheral cortical strands are virtually devoid of any phosphatase activity. In the central cortical masses a marked concentration of the enzyme is visible in the nucleus of the cells but cytoplasmic phosphatase activity is totally absent (Pl. X, fig. 2). The endothelium of the blood capillaries in the stroma also gives a negative reaction for the enzyme.

Adrenalin plus gonadotropic hormone treatment.—Gonadotropic hormone treatment entailed no perceptible change in the distribution of alkaline phosphatase in the capsule and in the peripheral cortical masses of the adrenalin-treated birds. However, appreciable amounts of cytoplasmic phosphatase are retained in the cells of the central cortical strands in addition to the pronounced activity of the enzyme observed in the nucleus of these cells (Pl. X, fig. 3). The endothelium of the stromal blood capillaries also gives a positive reaction for the phosphatase.

DISCUSSION.

The results of the present study indicate clearly that experimental hyperadrenalemia in the pigeon is associated with a marked reduction in adreno-cortical phosphatase activity. Gonadotropic hormone therapy in the adrenalin-treated birds is only partially effective in preventing this enzymatic loss. This is evidenced by the fact that only the central masses and the endothelium of the stromal capillaries show normal distribution of the enzyme but in the rest of the cortical components the phosphatase is prominently absent. Possibly, a higher dosage level of gonadotropic hormone would have been more effective in preventing this loss of phosphatase activity in the cortex of the adrenalin recipients.

It has been reported previously that sex hormone treatments cause pronounced inhibition of phosphatase activity in the adrenal cortex of this species (Kar, 1950a).

However, the degree of this inhibition is more well marked in the birds receiving estrogen than in the androgen-treated ones. In the former group there is an overall loss of enzyme activity from all the cortical components with the exception of the capsular blood vessels which continue to give a positive reaction in the endothelium. The situation, as we see, has an interesting parallel in the present experiment. Here, adrenalin treatment also caused a comparable reduction of phosphatase activity from the component tissues of the adrenal cortex. It should be recalled in this connection that the action of desoxycorticosterone or its close chemical ally, progesterone, is marked augmentation of enzymatic activity in the pigeon's adrenal cortex (Kar, 1950b).

There are a number of previous reports on inhibition of phosphatase activity by hormonal and other agents. Thus, androgen treatment causes a reduction of enzymatic concentration in the avian uropygial gland (Kar, 1950c). Progesterone administration results in a likewise loss of phosphatase activity in the female genital system of the same species (Kar, 1950d). Injection of desoxycorticosterone acetate into juvenile sparrows is associated with a pronounced enzymatic loss from the testicular tissues (Kar, 1950b). Addition of KCN in the substrate is followed by a definite inactivation of renal and intestinal alkaline phosphatase (Emmel, 1946). The present findings, therefore, fall well in line with these reports and further indicate that this enzymatic inhibition in the pigeon's adrenal cortex caused by adrenalin, may be obviated to some extent by gonadotropic hormone therapy.

SUMMARY.

Injection of adrenalin causes a loss of alkaline phosphatase activity in the pigeon's adrenal cortex. Gonadotropic hormone therapy is only partially effective in preventing this enzymatic loss. The similarity of action between the sex hormones and adrenalin in influencing the phosphatase concentration of the avian adrenal cortex is pointed out and discussed.

PART VIII. STUDIES IN THE DISTRIBUTION AND CONCENTRATION OF ALKALINE PHOSPHATASE IN THE TESTES OF NORMAL AND OF SEX HORMONE-TREATED PIGEONS.

INTRODUCTION.

The cytochemical localization of alkaline phosphatase has been made in the testes of some mammals and in that of the sparrow. In the rat this enzyme occurs in both the tubules and in the intertubular tissue (Dempsey *et al.*, 1949). After hypophysectomy the phosphatase disappears from the testicular components but replacement therapy with whole pituitary powder causes a return of the enzyme to its original distribution and intensity in all the elements. Wislocki (1949) demonstrated the presence of alkaline phosphatase in the testis of two species of deer, *Odocoileus virginianus borealis* and *Cervus nippon*.

In the testes of juvenile sparrows the enzyme is present in the seminiferous tubules and in the endothelium of the interstitial blood vessels (Kar, 1950b). Desoxycorticosterone acetate treatment causes a marked loss of phosphatase activity from practically all the testicular components.

The present report is concerned with an attempt to study the distribution and concentration of alkaline phosphatase in the testes of normal and of sex hormone-treated pigeons.

EXPERIMENTAL PROCEDURE.

Adult male pigeons were used in this study. A total of 12 birds were experimented on, of which 4 were injected with estrogen, 3 with androgen, and the remaining 4 were left uninjected to serve as controls. The birds were housed in cages and maintained under uniform husbandry conditions throughout the duration of the experimental period.

Testosterone propionate in sesame oil was administered intramuscularly. The daily injections (2 mgm.) were made into the breast muscles and continued for a period of 10 days. An equal amount of estradiol dipropionate (2 mgm.) was injected in a similar manner and over the same period of time. The sites of injection alternated on successive days between the right and left sides of the breast.

Autopsy followed 24 hours after the final treatments. The testes were carefully dissected out and fixed immediately in chilled 80% ethyl alcohol and in Bouin's fluid. Serial paraffin sections of the organ fixed in ethyl alcohol were prepared and processed according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. For routine histological observations the sections of the tissue fixed in Bouin's fluid were stained with Ehrlich's hematoxylin followed by alcoholic eosin.

RESULTS.

Controls.—The histological picture is typical of a mature testis at its height of spermatogenetic activity. The presence of large seminiferous tubules with successive stages of transformation of the epithelium into spermatogonia, spermatocytes, spermatids and spermatozoa are clearly seen in the sections. The basement membrane of the tubules contains small amounts of alkaline phosphatase. In the cellular elements of the tubules the enzyme activity is more pronounced in the nucleus than in the cytoplasm (Pl. X, fig. 4). The chromosomes of the dividing tubular elements also show positive reactions for the phosphatase. In the inter-tubular tissue the maximal concentration of the enzyme is seen in the endothelium of the blood vessels. Among the cellular elements of the interstitium, the Leydig cells exhibit marked activity of the phosphatase in the nucleus but less so in the cytoplasm. However, uniform nuclear and cytoplasmic enzyme activities are a notable feature of the fibroblast cells of this region.

Androgen treatment.—Histological changes more or less similar to those reported by Kar (1949) in the testis of this species after androgenic treatment are also seen in the present material. A definite retardation of spermatogenic activity and marked atrophy of the cellular elements are clearly evident upon microscopical examination. The basement membrane of the seminiferous tubules gives a negative reaction for the phosphatase. An overall reduction in enzyme activity from the various tubular elements is visible (Pl. X, fig. 5). However, in most instances the phosphatase has totally disappeared from the cytoplasm of these elements but the nuclear enzyme activity is retained to some extent. In the interstitium there is a predominance of fibroblasts over the Leydig cells. The latter show signs of atrophy and a reduction in the amount of phosphatase. The enzyme activity is also inhibited in the fibroblast cells. The endothelium of the interstitial blood vessels, however, shows a total loss of the enzyme.

Estrogen treatment.—Estrogen treatment has induced extreme atrophic condition in the testicular elements. The seminiferous tubules show a shrunken appearance and a degenerated state of the cellular elements. The phosphatase is totally absent from the tubular components (Pl. X, fig. 6). In the interstitium the almost total absence of the Leydig cells is a prominent feature. A slight activity of the enzyme is discernible in the fibroblast cells but there is a complete disappearance of the phosphatase from the endothelium of the interstitial blood vessels.

DISCUSSION.

The distribution of alkaline phosphatase in the testis of the pigeon differs in some respects from that in the mammals. In the rat (Dempsey *et al.*, 1949) the most prominent reactions for the enzyme occur in the spermatids and in a zone of almost hairline sharpness in the basement membrane surrounding the seminiferous

tubules. The nucleus of the spermatogonia and the chromosomes of the spermatocytes also exhibit moderate activity of the phosphatase. Variable amounts of the enzyme are present in the interstitium. Of the various elements in this region the endothelium of the blood vessels alone shows marked phosphatase activity. The distribution of the enzyme in testis of two species of deer studied by Wislocki (1949), exhibits a pattern which is more or less similar to that in the rat. In the species under report, however, it is evident that the phosphatase activity is practically uniform in the cellular elements of the seminiferous tubules and not localized in the spermatids as in the mammals. Moreover, appreciable amounts of the enzyme are also present in the Leydig and fibroblast cells of the interstitium in contrast to the almost negligible activity of the phosphatase visible in the mammalian counterpart of these cells.

It has been reported previously that desoxycorticosterone acetate treatment causes marked inhibition of phosphatase activity in the testis of juvenile sparrows (Kar, 1950*b*). In the present material also we observed that sex hormone injections are associated with a pronounced loss of enzyme activity from the various testicular components. Moreover, the histological changes encountered after hormonal treatments are clearly indicative of a suppressive action of the sexual hormones on both the gametogenic and endocrine activities of the testis. If these histological findings are reckoned against those on phosphatase reactions it would appear that some important physiological relationship exists between the hormonal-induced inhibition of testicular functions and the concomitant loss of phosphatase activity from the component tissues of this organ. However, we feel that pending further studies, no definite comments could be made at this stage on the specific rôle that the enzyme might play in the testis of sex hormone-treated pigeons.

SUMMARY.

Alkaline phosphatase is demonstrable cytochemically in the seminiferous tubules and in the interstitium of adult pigeon's testis. Sex hormone-treatments cause a pronounced loss of enzyme activity from the testicular components. The possible significance of this enzymatic change after hormonal treatments is pointed out and discussed.

ACKNOWLEDGMENTS.

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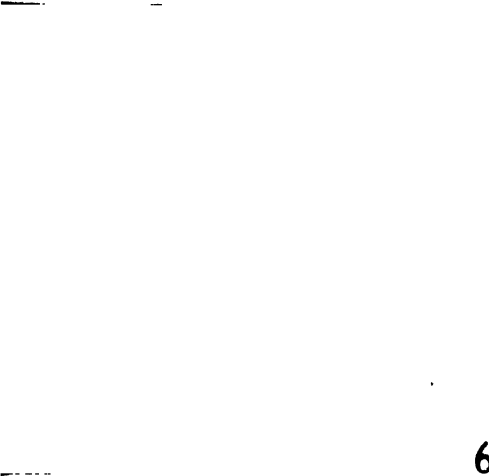
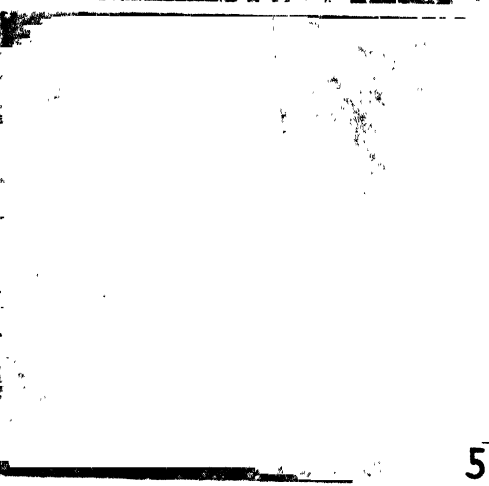
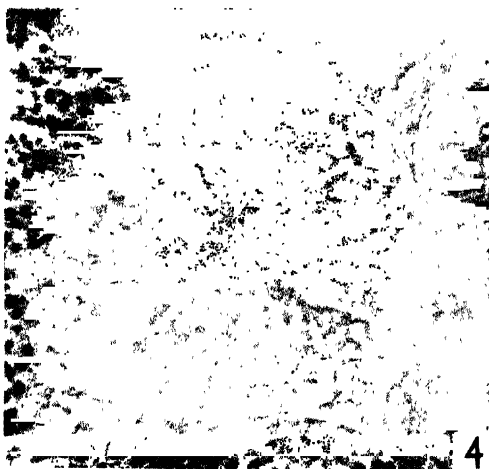
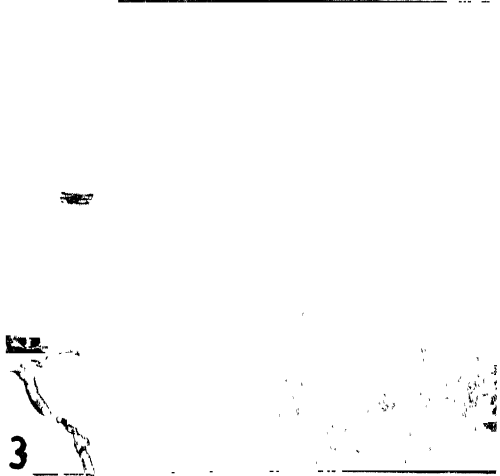
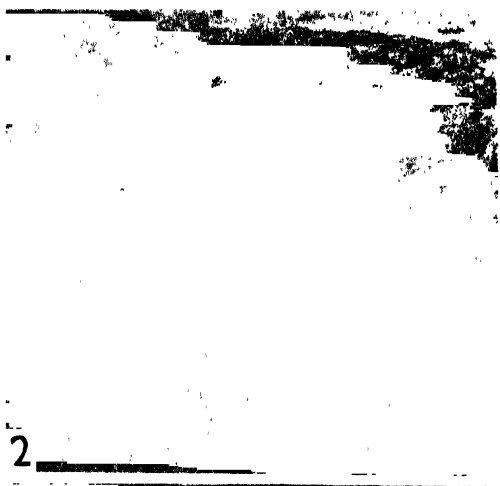
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EXPLANATION OF PLATE X.

(All figures are photomicrographs and are magnified $\times 130$.)

- FIG. 1. Section through the adrenal gland of a control pigeon. Cortical strands from the central region of the gland are shown. Note the marked phosphatase activity in the strands.
- FIG. 2. Section through the adrenal gland of an adrenalin treated pigeon. Some central cortical strands are shown. Note the nuclear phosphatase activity.
- FIG. 3. Section through the adrenal gland of an adrenalin plus gonadotropic hormone treated pigeon. Both the nuclear and cytoplasmic phosphatase activity can be seen. Compare with fig. 2.
- FIG. 4. Section through the testis of a control pigeon. Note the phosphatase activity in the testicular tissues.
- FIG. 5. Section through the testis of an androgen treated pigeon. Note the atrophic nature of the organ and the overall reduction in phosphatase activity from the component tissues.
- FIG. 6. Section through the testis of an estrogen treated pigeon. Note the extreme atrophic nature of the testis and the total absence of the phosphatase from the testicular components.



NEW EVIDENCE AGAINST A PROGESTERONE-LIKE ACTION OF ASCORBIC ACID.

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INTRODUCTION.

It is well known that ascorbic acid is present in the corpus luteum and that its concentration increases in the uterus during progestational changes due to the action of progesterone (Pincus and Berman, 1937). Kramer *et al.* (1933) reported that lowered concentration of ascorbic acid in the guinea-pig can prevent proper progestational proliferation. These authors further observed that the removal of this vitamin from the diet of a pregnant guinea-pig can cause abortion. These evidences led Israel and Meranze (1941) to suspect that ascorbic acid is associated with progesterone in bringing about progestational proliferation and that even alone it may be able to cause similar changes. In their experiments on infantile rabbits these authors actually demonstrated that vitamin C has progesterone-like effect on the uterus. However, Pratt (1943) carefully repeated Israel and Meranze's experiments but could not obtain any evidence whatsoever of a luteoid-like action of ascorbic acid.

From a review of the above works it becomes evident that ascorbic acid has some interesting rôle to play in uterine physiology. We, therefore, decided to open up the problem once again and to determine whether this vitamin has any progesterone-like action. We used female pigeon as the material in our studies because we felt that it would be worth while to provide data on this rather disputed point from an altogether different species of animal. Moreover, the physiological action of progesterone on the genital system of the female pigeon is well known (Kar, 1949a) and, therefore, it occurred to us that it would be interesting to compare the actions of this vitamin and the luteoid on the female genital system of this avian species.

EXPERIMENTAL.

Adult female pigeons were used in this study. A total of 15 birds were experimented on, of which a group of 5 were left uninjected to serve as controls. A second group of 5 birds were injected intramuscularly with ascorbic acid ('Cevalin', ~~Er~~ Lilly Co., Indianapolis, U.S.A.). The daily injections (50 mgm.) were made into the breast muscles and continued for a period of 7 days. The remaining lot of 5 birds were first injected with diethylstilbestrol (5 mgm. daily for 4 days) and subsequently treated with ascorbic acid at the rate of 50 mgm. daily for 7 days. All the birds were kept in cages and maintained under uniform husbandry conditions throughout the duration of the experimental period.

Autopsy followed 24 hours after the final injections. The ovary and the oviduct were carefully dissected out, weighed to the nearest mgm., and finally fixed in alcoholic Bouin's fluid for histological studies. Serial sections, 6 microns in thickness were prepared by the paraffin method and stained with Ehrlich's hematoxylin followed by eosin.

RESULTS AND CONCLUSION.

Controls.—Gross examinations at autopsy revealed a condition which is typical of the ovary of an adult bird. The presence of a number of large follicles and innumerable smaller ones are the notable macroscopic features of the organ. The larger follicles are full of yolk and are extremely hyperemic. The oviduct is a very conspicuous structure which occupies the major part of the peritoneal cavity. The convolutions of the duct are an index to its remarkable length. The entire organ is also richly vascularized.

Histological examination confirms the macroscopic findings that the ovary is in a state of full activity. The larger follicles are full of yolk and the follicular epithelium shows a high degree of stratification. The smaller follicles exhibit various stages of cytosomal differentiation. The interfollicular connective tissue is extremely well developed and a marked vascularity is also evident. Microscopical examinations of the oviduct show that the organ is at its height of secretory activity. The serosa, muscularis, and the sub-mucosa are extremely well developed. The endometrium shows pronounced glandular activity and a bordering epithelium of the stratified variety. The oviducal lumen exhibits a tortuous condition owing to the inward projection of the villus-like folds of the endometrium. The sub-mucosal connective tissue extends throughout the axial portion of these folds and in between the endometrial glands. A pronounced hyperemic condition of the duct is also visible.

Ascorbic acid treatment.—Progesterone has marked inhibitory effects on the genital system of the female pigeon (Kar, 1949a). The luteoid causes suppression of the follicular growth and pronounced infantilism of the oviduct. No such inhibitory effects are, however, visible in the genital system of the present material after ascorbic acid treatment. Gross appearance of the ovary is similar to that of the control birds. The organ is full of large and small follicles. There are no indications, whatsoever, of any hypoplastic change which, however, is to be expected if the vitamin acted like the luteoid on the ovary. Further, no signs of infantilism could be detected in the oviduct. The macroscopic features of the latter are comparable in every way with those of the oviduct of an adult bird. Histological examinations of the ovary and the oviduct also confirm our macroscopic findings. The microscopic appearance of these organs is similar to those of the ovary and the oviduct of the control pigeons and no inhibitory effects of the vitamin are discernible.

The above findings demonstrate clearly that unlike progesterone, ascorbic acid does not produce any inhibitory changes in the genital system of the female pigeon. The ovary and the oviduct of the vitamin-treated birds continue to remain unaltered histo-physiologically, and this is undoubtedly a very strong evidence against any luteoid-like action of vitamin C.

Ascorbic acid treatment in pigeons primed with estrogen.—We have already mentioned in a previous section that a batch of experimental birds were first treated with estrogen and subsequently with ascorbic acid. The object of this procedure was to expose only the oviduct to any possible luteoid-like action of the vitamin. It is well known that the ovarian function is suppressed by the action of estrogen but the secretory activity of the oviduct is stimulated to a very marked extent (*vide* Kar, 1949b). This procedure, therefore, served our purpose very well in targeting the effect of ascorbic acid exclusively on an experimentally-stimulated oviduct. To ensure accuracy, we examined the genital system of the estrogen-treated animals by laparotomy before the commencement of vitamin injections. The condition of the ovary, as we expected, was definitely infantile, but the oviduct was very much swollen and unusually hyperemic. Gross examinations at autopsy revealed similar conditions of the genital system. Histological examinations of the ovary showed that estrogen treatment caused inhibition of the follicular develop-

ment and atrophy of the stromal elements. Indications of estrogen-induced stimulation, however, were evident in the histological preparations of the oviduct. The serosa, muscularis and the sub-mucosa appeared greatly thickened. The endometrial glands were much enlarged in size and the oviducal lumen appeared to be clogged with the secretions of these glands.

The above findings are, undoubtedly, not indicative of any inhibitory action of ascorbic acid on the oviduct. It may be recalled here that progesterone has pronounced inhibitory action on the oviduct of this species (Kar, 1949a). The new evidence which we present in this report, therefore, appears to be against any progesterone-like action of ascorbic acid as described by Israel and Meranze (1941).

SUMMARY.

Ascorbic acid was injected intramuscularly into normal female pigeons and also into female pigeons previously primed with estrogen. Contrary to a previous report no effects similar to those of progesterone were obtained.

ACKNOWLEDGMENT.

The authors wish to express their indebtedness to Dr. B. Mukerji, Director, Central Drugs and Pharmacognosy Laboratories, for constant encouragement and keen interest in our work.

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ALLELES AND THEIR TIME OF EXPRESSION IN YEASTS.

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(Communicated by Prof. J. M. Sen, F.N.I.)

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INTRODUCTION.

In a recent contribution (Subramaniam, Ranganathan and Krishna Murthy, 1948) the various types of sculpturing observed in the giant colonies of the two-chromosome brewery yeast (Subramaniam, 1946) were classified into *Smooth I*, *Smooth II*, *Smooth III*, *Rough I* and *Rough II* in an ascending grade of complexity. On the basis of observations on reverse mutations, these sculptural differences were interpreted as caused by different allelic combinations, and that multiple alleles occur at the locus determining the nature of sculpturing. If the above classification into various sculptural types was a natural one, then, the highly sculptured *Rough II* colony should, during its development, show the other stages. That this might be so, was indicated by the changes recorded in Photos 15 and 16 in Plate III of that paper (Subramaniam, Ranganathan and Krishna Murthy, 1948). Some of the sectors which initially had concentric marginal striations characteristic of the *Smooth II* type developed radial ones also and thus had a lace-like texture (*Smooth III*). Minute granules developing on the lace-like texture transformed the sector to the *Rough I* category. The above colony was sectorized and hence could not be depended on for any definite conclusions.

There is a seasonal change in the population of the mutants in the cultures (Mallya and Subramaniam, 1949) and at the time the above observations were made, confirmation by extended experiments was not possible. The cultures were then composed purely of the *Smooth I* and *Smooth II* types.

MATERIAL AND METHODS

Proof for the existence of multiple alleles was attempted by exposure of the actively growing *Rough I* cells to ultraviolet irradiation. Transformation was possible not only to the *Smooth I* (Subramaniam and Krishna Murthy, 1948) but also to the *Rough II* condition (Subramaniam and Ranganathan, 1949). Nine strains were isolated after irradiation for four hours under a mercury arc at a distance of 90 cms. but early use of *Ragi Malt* instead of *Barley Malt* for giant colony media resulted in some of the colonies showing types of sculpturing not observed before. The composition of the media appeared to be a vital consideration in the classification of the types and the problem arose whether the composition affected merely the expression of the genes or whether *Ragi Malt* formed a selective environment (cf. Braun, 1947) for particular mutants. The seasonal variation in the type of sculpturing shown by the same irradiated strain during different months of the year (Subramaniam and Ranganathan, 1949) indicated that the composition of the medium affected only the expression of the genes. Therefore, it necessitated an extensive

series of investigations on the effect of the composition of the medium on the nature of sculpturing (Subramaniam and Ranganathan—unpublished). The observations on the time of expression of the different genes had to be kept in abeyance for eighteen months for a clear evaluation of the factors governing the nature of sculpturing of giant colonies.

Two of the strains obtained after ultraviolet irradiation, viz. BYU 4 and BYU 5 were used for these investigations. The method for the preparation of media is given elsewhere (Subramaniam and Ranganathan, 1948). *The colonies were grown at room temperature.*

OBSERVATIONS.

Immediately after isolation, BYU 4 gave a giant colony in Ragi Malt Agar as illustrated in Photo 1. Three months later, it gave an entirely smooth colony (Photo 2) in the same type of medium. Further tests were, therefore, carried out in March 1948 using Barley Malt Agar, since at that time the colony which developed was of the characteristic *Rough I* type.

The strain BYU 5 gave a smooth colony in December 1947 and January 1948 on Ragi Malt Agar (Photos 3 and 4). In March 1948 it resembled the strain BYU 4 in producing a *Rough I* colony in Barley Malt Agar. The growing colonies of these strains were closely watched and photographed on identical dates during the different stages of growth.

During the first six days of growth, the colonies of the two strains are almost smooth. On the eighth day the colony of the strain BYU 4 had the sculpturing shown in Photo 5. This appears to be intermediate between the *Smooth II* and *Smooth III*. The concentric and radial folds do not show the delicacy characteristic of the pure *Smooth II* and *Smooth III* colonies. The accelerated rate at which the various early types of sculpturing are passed through may be responsible for the crude replicas of the *Smooth II* and *Smooth III* varieties. On the 11th day, the colony had the characteristic appearance (Photo 6) of the *Rough I* illustrated as Photo 3 in Pl. 1 of the earlier paper (Subramaniam, Ranganathan and Krishna Murthy, 1948) on which the original description was based.

The appearance of the colony of BYU 5 on the eighth day was identical (Photo 7) with that of BYU 4 photographed on the same day. This colony got contaminated when opened for photography and hence further observations were made on the duplicate. Its transformation to the characteristic *Rough I* condition, however, was slower. The bold folds gradually gave rise to the *Smooth III* type of delicate lace-like texture and it was in this condition on the 11th day (Photo 8) when the BYU 4 colony had reached its final expression. It was only on the 15th day that BYU 5 reached the *Rough I* type of sculpturing (Photo 9). The remarkable similarity between Photos 6 and 9 is of immense significance. It has recently been discovered (Subramaniam and Krishna Murthy—unpublished) that not only the composition of the medium but also the quantity used, determines the nature and time of expression of the genes. The slightly slower appearance of the various stages in BYU 5 is not because of its slower growth rate, but due to the lesser quantity of nutriment available for growth.

DISCUSSION

Recovery of Types.—The recovery of the *Rough I* type in the ultraviolet irradiated strains almost during the same month as in the previous year emphasises that different gene mutants get established during the different months of the year. The predominance of the various mutants in the different strains of the two-chromosome control cultured under identical condition do not synchronise exactly

but are parallel. The recovery of the *Rough I* cells in the strains BYU 4 and BYU 5 simultaneously at a period when the *Rough I* cells were predominating in one of the control cultures (Krishna Murthy and Subramaniam—unpublished) indicates that parallel changes are occurring in cultures started with different gene mutants and that mutations and reverse mutations occurring at the locus get established because of their different viabilities and growth rate during the various seasons (Mallya and Subramaniam, 1949).

Skovsted (1943) emphasised that a species could originate in yeast by a single step mutation. Our irradiation experiments were initially planned to test the above possibility. Not only could we not obtain any confirmation of his claims, but on the other hand, the experiments offered proof for reverse mutations and the possibility of the recovery of the original types. His failure to observe reverse mutations and to recover the starting type should, therefore, be due to other causes. Skovsted (1943) mentions that a fresh sample of gelatine used in later stages of his experiments gave colonies of a differing appearance. The samples of lager wort are also stated to have varied from time to time. The lack of a proper realisation of the importance of these factors in giant colony expression may be responsible for his inability to recover the original types.

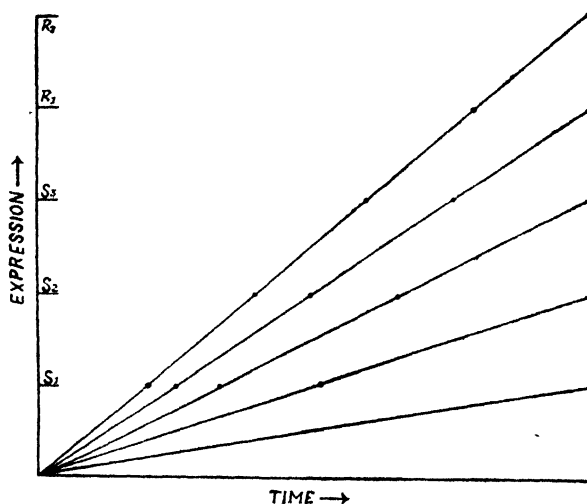
Very delicate populational problems have to be taken into consideration in evaluating the changes observed in giant colonies. To locate definitely the changes induced by ultraviolet irradiation, the giant colony changes have to be investigated immediately. Any delay would result in entirely missing the real picture. It is the type predominating during a particular season that is exposed to irradiation. Mutation is sporadic and if it results in a reversion to the original condition, this would outgrow the others because of its superior viability and growth rate and mask the picture altogether when cultured for a few days in liquid media.

Alleles and their Time of Expression.—Under standard conditions and after the lapse of a definite interval, the presence of the different alleles in the homo- and heterozygous condition produces an ascending grade of complexity in sculpturing. Since before the typical *Rough II* condition is reached, the giant colony passes through the *Smooth I*, *Smooth II*, *Smooth III* and *Rough I* stages, the following interpretation is possible.

Nature of Sculpturing.	Probable genic constitution.
Rough II	Rough/Rough
↑	↑
Rough I	Rough/Smooth or Rough/Lace
↑	↑
Smooth III	Lace/Lace
↑	↑
Smooth II	Smooth/Lace
↑	↑
Smooth I	Smooth/Smooth.

In cells homozygous for the *Smooth* gene, development stops at *Smooth I*, while in combination with *Lace* it proceeds a step further (*Smooth II*). When cells are pure for the *Lace* gene development proceeds to the *Smooth III* condition. A *Rough I* colony is produced when the cells are heterozygous for the *Rough* allele, while the entire colony is *Rough* when the cells are homozygous for the above gene.

The above observation is graphically demonstrated in an idealised fashion in Text-fig. 1. It would be seen that with increasing complexity of final expression,



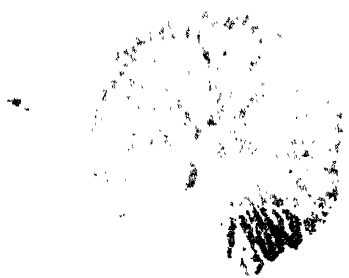
TEXT-FIG. 1.

the earlier types are not only pushed farther and farther back, but there is also a corresponding shortening of the time of duration of each stage.

The alleles could be arranged in the following order from their effect on sculpturing: Smooth \rightarrow Lace \rightarrow Rough. Can we consider that the relation between these is just like that between typical hypo- and hypermorphs? Judged from the complexity of sculpturing they produce, such a conclusion is justifiable. On the basis of observations on reverse mutations, it was suggested (Subramaniam, Ranganathan and Krishna Murthy, 1948) that these genes are allelomorphic and just as in the case of some series of allelomorphs in *Drosophila* (Stern, 1930; Waddington, 1939) these also show different efficiencies and could be considered to be related to one another as hypo- and hypermorphs. As in *Drosophila*, this relation is limited only to the effect on sculpturing, and the identical genes have entirely different effects on viability and rate of growth during the different seasons. It has to be remembered that when cultured at room temperature, the *Rough* types predominate during the hot months and the *Smooth* varieties during the colder ones.

From transplantation experiments on *Drosophila* (Beadle and Ephrussi, 1937), it has been suggested that the development of the wild type of pigmentation in the eye is the result of a chain of reactions and the inter-relationships between the eye colour genes have been evaluated on the basis of the observed end results. Waddington (1939) comments: 'In all the cases so far mentioned, the gene-controlled substances are only observed after a long series of developmental processes has occurred, and it is not by any means clear that these end-products are directly produced by the genes concerned; it is therefore not safe to assume that the nature of the observed substances gives any clue to the nature of the genes' (p. 179). In the case of the multiple allelomorphs in our control yeast strain are we on much surer grounds? The giant colony of yeast is a mere aggregation of cells and the mode of sculpturing is determined by the size, shape and mode of budding of the cells. The mutant genes determine the above characters whether cultured in solid or liquid media, and when giant colony inoculations are carried out, the slowly changing environment during the growth of the colonies and the reaction of the cells homo- and heterozygous for the different genes determines the final type of sculpturing.

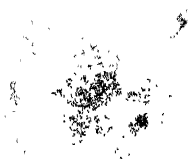
It appears probable, therefore, that the allelomorphic genes in yeasts differ only in their relative efficiencies. There is no reason whatever to consider yeast as unique either cytologically or genetically.



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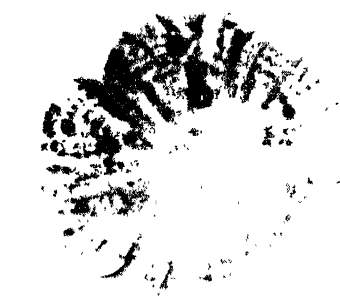
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SUMMARY.

1. The various types of sculpturing observed in giant colonies of the two-chromosome brewer's yeast could be classified into distinct types in an ascending grade of complexity. This classification is shown to be a natural one on the basis of observations on types exhibiting finally a complex sculpturing.

2. The simpler types appear as orderly stages during development of the complex ones. Photographs illustrating such stages are given from two strains isolated after ultraviolet irradiation and having different early histories.

3. The same types could be recovered year after year and the failure of the early workers in this direction may be due to a lack of realisation of the effect of the environment on genic expression in giant colonies.

4. The multiple alleles occurring at the locus governing the nature of sculpturing appear to be related to one another as hypo- and hypermorphs. It is indicated diagrammatically how with increasing complexity of final expression, the earlier types are not only pushed farther and farther back, but that there is also a corresponding shortening of the time of duration of each stage.

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DESCRIPTION OF PHOTOGRAPHS.

PLATE NO. XI.

- Photo 1. BYU 4. 14-day growth on Ragi Malt Agar. 3.3 cms. 10-10-47.
 Photo 2. BYU 4. 22-day growth on Ragi Malt Agar. 2.9 cms. 22-1-48.
 Photo 3. BYU 5. 25-day growth on Ragi Malt Agar. 2.3 cms. 10-12-47.
 Photo 4. BYU 5. 20-day growth on Ragi Malt Agar. 2.4 cms. 26-1-48.
 Photo 5. BYU 4. 8-day growth on Barley Malt Agar. 2.3 cms. 5-3-48.
 Photo 6. BYU 4. Same colony after 11 days growth. 2.6 cms. 8-3-48.

PLATE NO. XII.

- Photo 7. BYU 5. 8-day growth on Barley Malt Agar. 2.5 cms. 5-3-48.
 Photo 8. BYU 5. 11-day growth on Barley Malt Agar. 3.0 cms. 13-3-48.
 Photo 9. Same colony after 15 days of growth on Barley Malt Agar. 3.3 cms. 16-3-48.

FOSSIL MICROFLORA FROM THE MOHGAON KALAN BEDS OF THE MADHYA PRADESH, INDIA.

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(With three Plates and twenty-eight text figures.)

Communicated by Prof. G. P. Majumdar, F.N.I.

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INTRODUCTION.

The investigation of the fossil microflora has attained considerable importance in recent years and much work has been turned out on this subject in Europe and America. In India work has been done on the fossil microflora by Virkki (1946), Wodehouse (1935¹), Ghosh and Sen (1948), Sahni, Sitholey, and Puri (1947), and Sahni (1941). Sahni, Sitholey and Puri (1947) have described the microflora from the Tertiary beds of Assam series. Ghosh (1941) studied remains from Tertiary rocks of Assam, Rao and Vimal (1950) from Palana Lignite, Eocene, Bikaner, and Sen (1948) from Assam coalfields.

The fossil cherts from the Mohgaon-Kalan beds were investigated by me for their microflora and were found to be so rich in the organic remains that every drop of the maceration fluid brought with it on the slide some new type. In the first maceration, some fungal fructifications, bits of sclerenchymatous tissues, hairs, fungal hyphae, four celled spores of Thallophyta, masses of spores, etc. (Chitaley, 1950), were discovered. During the present investigation different kinds of spores, pollen grains and some other organic micro-remains were discovered, which are described in this paper. The material came from the Deccan Inter-trappean beds exposed near the village Mohgaon-Kalan, Chhindwara district, Madhya Pradesh, India, probably of Eocene age.

TECHNIQUE.

Some of the promising pieces of cherts were first macerated with Schultze's maceration fluid (HNO_3 and KClO_3), but the treatment was found to be unsuccessful. Hydrofluoric acid was next tried and it macerated the rock easily. The slides were prepared taking every care not to allow any foreign matter or atmospheric ingredients to enter. For preparing the permanent mounts glycerine jelly (Wilson, 1946), was found to be unsatisfactory. In the absence of euparal and diaphane, the permanent preparations were made in canada balsam.

Classification and Nomenclature of the Spores.

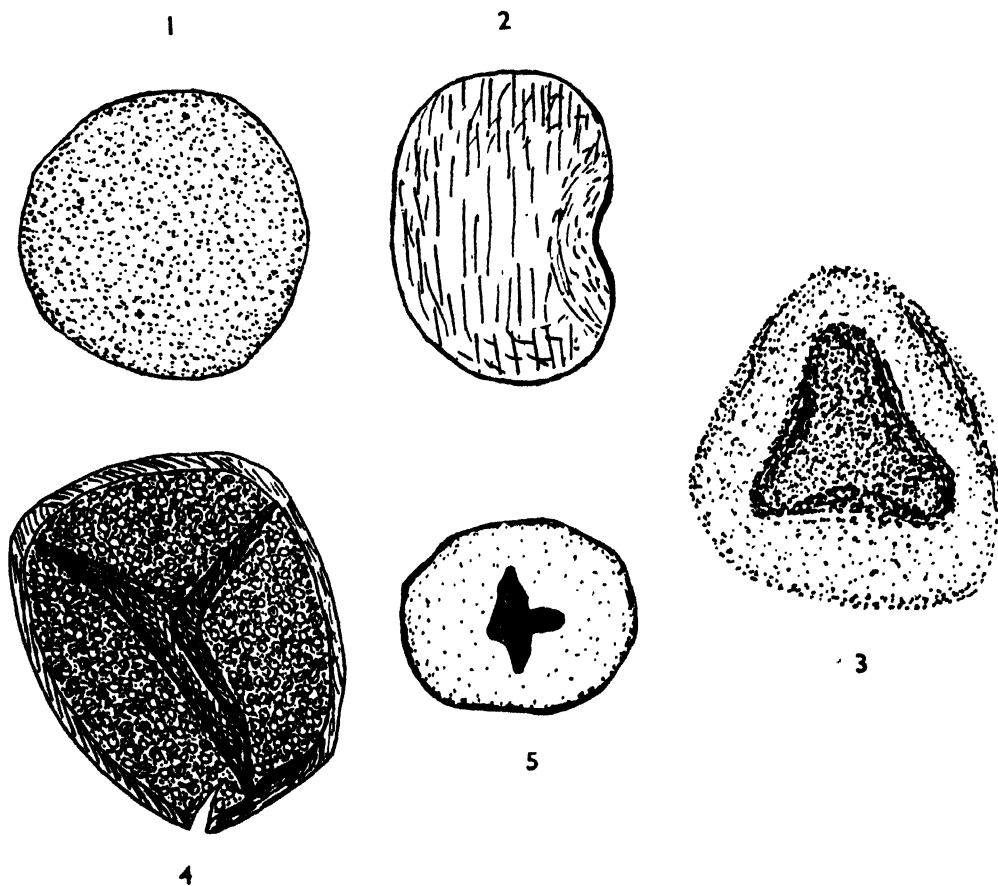
At the meeting of the palaeobotanists working in India, held under the auspices of the Palaeobotanical Society at the Institute of Palaeobotany, Lucknow, in January, 1949 (*Science and Culture*, 14, 463-465, 1949), it was decided to adopt a system of classification of spores and pollen grains on the lines adopted by Naumova (1937). In the absence of the availability of Naumova's detailed literature, I have adopted the provisional classification as well as terminology recently introduced by G. Erdtman (1947) as it is found to be most convenient. An attempt has been

made to give a detailed description of the microflora studied. Some of the spores and pollen grains have been also compared with recent types.

DESCRIPTION.

Spores of Pteridophyta.

Five different types of spores have so far been observed. It is rather difficult to identify the particular spore, as the same type may belong to different genera, or one genus may have different types of spores (Knox, 1938; and Selling, 1946).



TEXT FIGURES 1-5. Pteridophytic spores. \times Ca. 1200.

- FIG. 1. *Alites* spm.
- FIG. 2. *Monolites* spm.
- FIG. 3. *Trilites* spm.
- FIG. 4. *Trilites* spm.
- FIG. 5. *Trilites* spm.

ALITES (Erdtman, 1947).

Alites spm. (Pl. XIII, fig. 1; text fig. 1)—Spore spheroidal, tetrad scar absent; wall of the spore thin and smooth; matrix granular; size 30μ .

MONOLITES (Erdtman, 1947).

Monolites *spm.* (Pl. XIII, fig. 2; text-fig. 2).—Spore concavo-convex, monolete, aperinate, exposed in the lateral view; wall smooth and thin; $32\mu \times 24\mu$. Monolete spores are generally found in Polypodiaceae. This specimen looks like a naked spore without a perine, showing similarity to a polypodiaceous spore. Some of the spores of Gleicheniaceae also resemble the present specimen (Knox, 1938).

TRIILITES (Erdtman, 1947).

Trilites *spm.* (Pl. XIII, fig. 3; text fig. 3).—Trilete, triangular with rounded angles and fairly straight sides; matrix granular, 28μ .

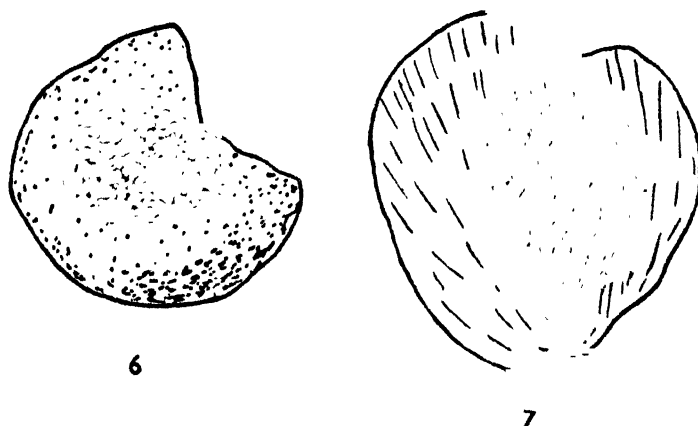
Trilites *spm.* (Pl. XIII, fig. 4; text-fig. 4).—Trilete, subtriangular with convex sides; tetrad scar by prominent ridges extending and narrowing down to the periphery; wall of the spore slightly thick and smooth, $39.5\mu \times 32\mu$.

Trilites *spm.* (Pl. XIII, fig. 5; text-fig. 5).—Trilete, spheroidal to elliptical; tetrad scar prominent; wall of the spore smooth or slightly granular, thin, $24\mu \times 20\mu$.

Pollen grains of Spermatophyta.

GYMNOSPERMAE.

Pollen grains of gymnosperms are very rare; only two of them have been observed so far.



TEXT-FIGURES 6 and 7. Gymnospermous spores. \times Ca. 1200.

FIG. 6. *Monosaccites* *spm.*

FIG. 7. *Disaccites* *spm.*

Monosaccites *spm.* (Pl. XIII, fig. 6; text-fig. 6).—One-winged grain, wing broad bladder-like, torn on one side; body sub-triangular to spheroidal; whole grain $24\mu \times 20\mu$; body, $12\mu \times 12\mu$.

Disaccites *spm.* (Pl. XIII, fig. 7; text-fig. 7).—Two-winged, wings broad, attachment marginal; body elliptical; body $24\mu \times 12\mu$; left wing, $28\mu \times 7\mu$; right wing, $24\mu \times 5\mu$.

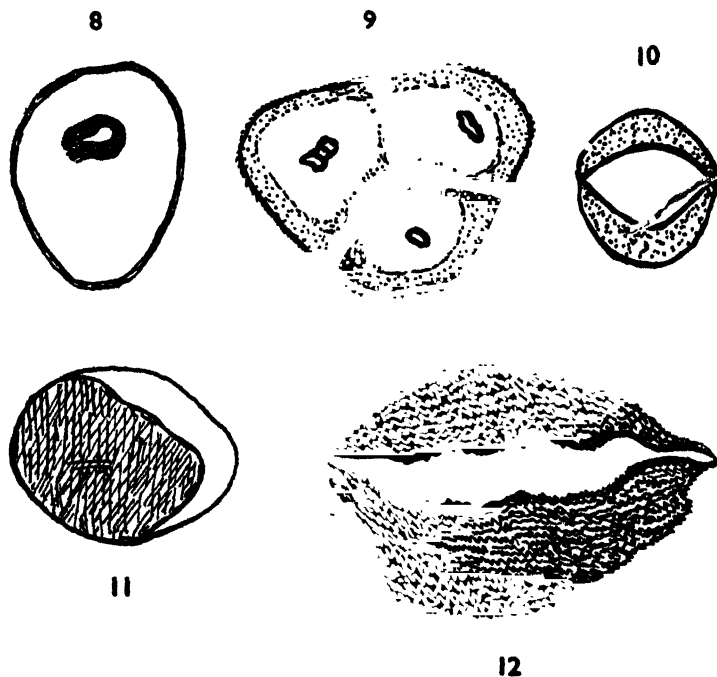
ANGIOSPERMAE.

Pollen grains of angiosperms appear to predominate over all others. They are very many and belong to different groups. As the age of the bed is Tertiary, there is no surprise that the angiospermic grains outnumber all other types.

MONOCOTYLEDONEAE.

Monoporites (*Graminidites*) *minor*, (text-fig. 8).—The grains are small, elliptical, broad at one end and narrow at the other; pore single surrounded by a rim approximately 1.2μ in width; exine thin and smooth; length 21.5μ .

The monoporites grains with a distinct poral rim are characteristic of Gramineae but according to Erdtman, 1944, they are not restricted to Gramineae alone and hence the name 'Graminidites' has been used to show only the similarity.



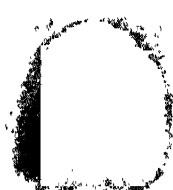
TEXT-FIGURES 8-12. Monocotyledonous pollen grains. \times Ca. 1200.

- FIG. 8. *Monoporites* (*Graminidites*) *minor*.
 FIG. 9. *Tetrado-Monoporites* (*Typhidites*) *spm.*
 FIG. 10. *Monosulcites* (*Palmidites*) *minima*.
 FIG. 11. *Monosulcites* (*Palmidites*) *media*.
 FIG. 12. *Monosulcites* (*Palmidites*) *spinosa*.

Tetrado-monoporites (*Typhidites*) *spm.* (Pl. XIII, fig. 8; text-fig. 9).—Grains united in tetrads, three are seen in this view; each one is elliptical to spherical with a smooth or faintly warty exine; germinal pore single; size of each grain 16μ .

Monosulcites (*Palmidites*) *minima*, (Pl. XIII, fig. 9; text-fig. 10).—Grain small, monosulcate, spheroidal; exine smooth, furrow single reaching from end to end; $14.5\mu \times 14.5\mu$. More or less rounded, monosulcate grains are observed in some palms by Selling (1947, pp. 334-337). Such type of grains are many in number, also present in some of the peel sections.

Monosulcites (*Palmidites*) *media*, (Pl. XIII, fig. 10; text-fig. 11).—Lateral view of a monosulcate grain, furrow single, invaginating from end to end. This grain is almost similar to the above grain, 'Monosulcites minima' but larger in size, with a long furrow, $16\mu \times 16\mu$.



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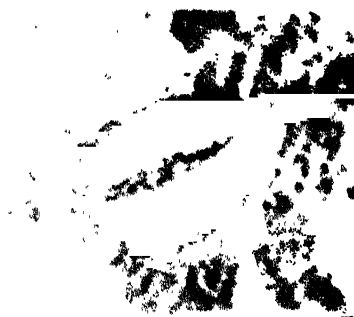
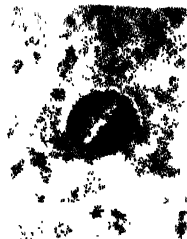


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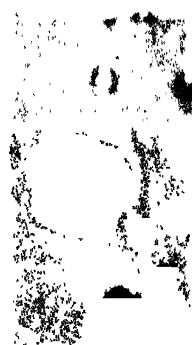
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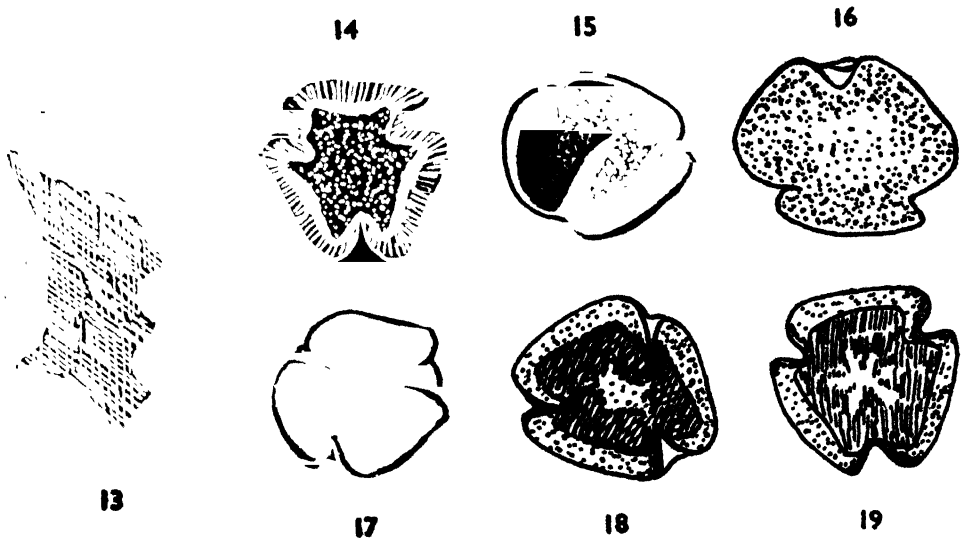
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Monosulcites (Palmidites) spinosa. (Pl. XIII, fig. 11; text-fig. 12).—Grain comparatively large, elliptical or boat-shaped, sulcus single going from end to end, with thick spiny ridges; exine spiny, spines short, $36\mu \times 24\mu$.

As many palm stems and roots have been discovered from the same bed (Rode, 1933), from where the Cherts for maceration were collected, there is every possibility that all the above three types of monosulcate grains described, belong to the same family Palmaceae. Still the name *Palmidites* is maintained which implies similarity alone, of the above grains to those of palms.

DICOTYLEDONEAE.

Monosulcites spm. (Pl. XIII, fig. 12; text-fig. 13).—Grain monosulcate, elongated or elliptical; furrow wide and long; $32\mu \times 24\mu$.



TEXT-FIGURES 13-19. Dicotyledonous pollen grains. \times Ca. 1200.

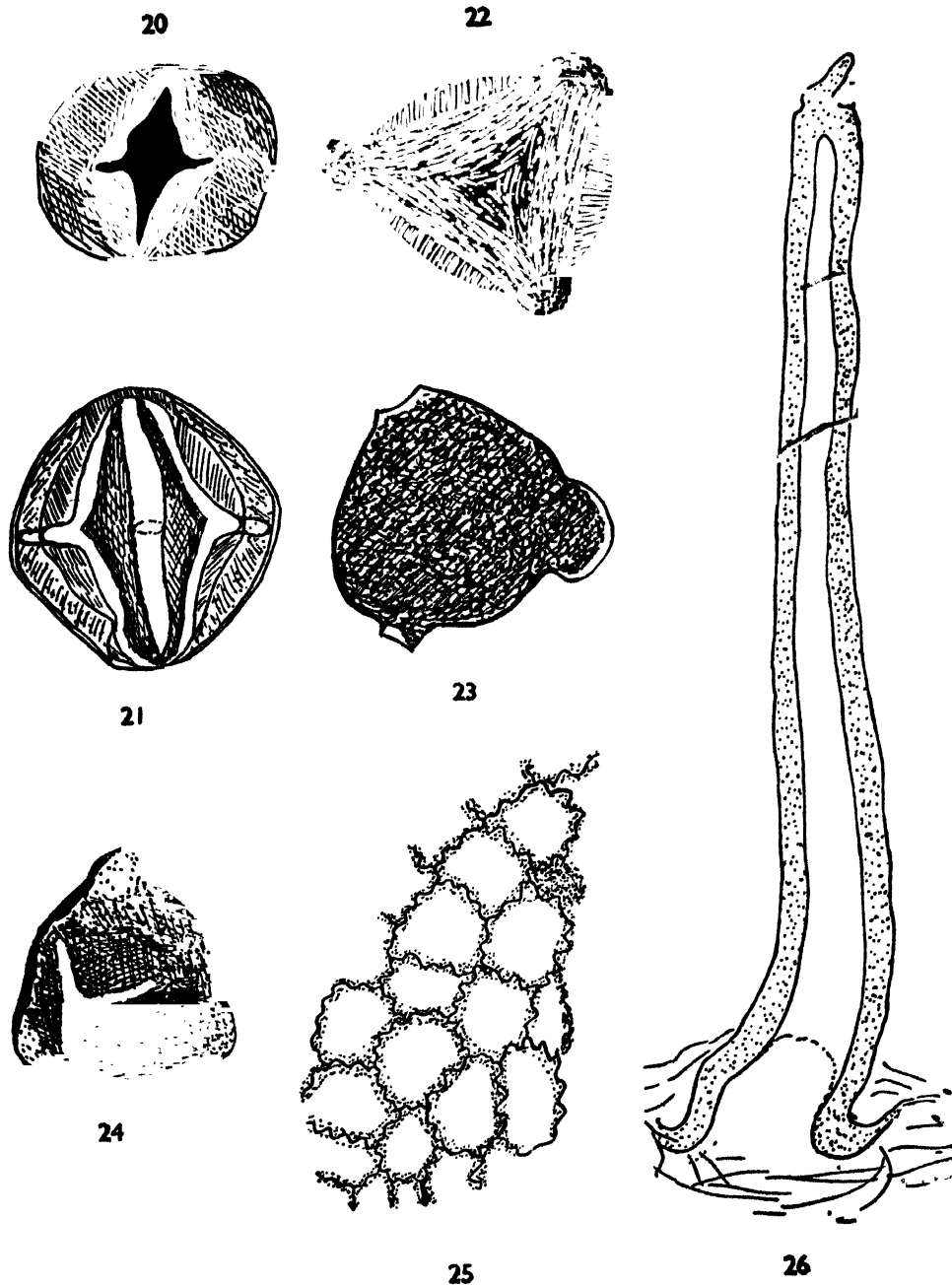
- FIG. 13. *Monosulcites* spm.
 FIG. 14. *Tricolpites (Rhamnacidites)* spm.
 FIG. 15. *Tricolpites* spm.
 FIG. 16. *Tricolpites* spm.
 FIG. 17. *Tricolporites (Myrtacidites)* spm.
 FIG. 18. *Tricolporites* spm.
 FIG. 19. *Tricolporites* spm.

Tricolpites (Rhamnacidites) spm. (Pl. XIII, fig. 13A; text-fig. 14).—Grain small; tricolpate, triangular in the polar view with three short, broad furrows; exine psilate and thick; germinal pores not distinct. The walls of the three colpae are straight or slightly concave; polar view, 20μ .

Tricolpites spm. (Pl. XIII, fig. 13B; text-fig. 15).—Grain tricolpate, subtriangular; furrows deep; exine not very thick, psilate; germinal pores indistinct, polar view, 17.5μ .

Tricolpites spm. (Pl. XIII, fig. 14; text-fig. 16).—Grain tricolpate, subtriangular; furrows short; matrix of the grain granular; exine thin and psilate; polar view; size 21.5μ .

Tricolporites (Myrtacidites) spm. (Pl. XIII, fig. 15; text-fig. 17).—Grain small, tricolporate, subtriangular in the polar view; furrow deep; exine not very thick,



TEXT-FIGS. 20-26. Dicotyledonous pollen grains. \times Ca. 1200.

FIG. 20. *Tricolporites* (*Rosacidites*) *sp.*

FIG. 21. *Tricolporites* *sp.*

FIG. 22. *Triorites* (*Betulacidites*) *sp.*

FIG. 23. *Triorites* (*Betulacidites*) *sp.*

FIG. 24. *Triorites* (*Lythracidites*) *sp.*

FIG. 25. A piece of cuticle with sinuous walled cells.

FIG. 26. A unicellular hair.

- psilate; germinal pores three, one at each angle, each crossed by a transverse endexinous membrane; polar view, 17.5μ .
- Tricolporites* spm. (Pl. XIV, fig. 16; text-fig. 18).—Tricolporate grain, subtriangular; ~~exine~~ ~~exine~~ thick, psilate; sides of the colpae somewhat straight; furrows more or less deep, each with a germinal pore; polar view, 18μ .
- Tricolporites* spm. (Pl. XIV, fig. 17; text-fig. 19).—Grain tricolporate, subtriangular; furrows short; germinal pore indistinct; walls of the three colpae slightly convex; exine thick, psilate. Polar view, 20μ . This grain differs from the previous one in the larger size, shorter furrows, walls of the colpae being convex, and the pores being indistinct.
- Tricolporites* (*Rosacidites*) spm. (Pl. XIV, fig. 18; text-fig. 20).—Grain tricolporate, equatorial view exposed, slightly flattened, the furrow extending almost from end to end surrounded by a thick ridge, germinal pores present: exine of the grain thin and psilate; $22\mu \times 17.5\mu$.
- Tricolporites* (*Rosacidites*) spm. (Pl. XIV, fig. 19).—Grain tricolporate, spherical, equatorial view exposed; furrows extending from end to end, germinal pores very prominent, exine thick and psilate; $20\mu \times 17\mu$.
- Tricolporites* spm. (Pl. XIV, fig. 20; text-fig. 21).—Tricolporate grain, somewhat spheroidal, furrows with prominent germinal pores; furrows quite long; equatorial view; $26\mu \times 24\mu$.
- Triorites* (*Betulacidites*) spm. (Pl. XIV, fig. 21; text-fig. 22).—Grain subtriangular to spheroidal in polar view; arci sharp; germinal pores three, each one represented by an elliptical prominent bulge of the intine; texture of the general surface of the exine smooth. This grain resembles very much a grain of Betulaceae described by Kirchheimer (1932); size 22.5μ .
- Triorites* (*Betulacidites*) spm. (Pl. XIV, fig. 22; text-fig. 23).—Grain triorate, oblique view, approximately triangular. In polar view more or less angular owing to the aspidate pores; pores three; exine faintly reticulate; Possibly belongs to Betulaceae—*Betula*. (Erdtman 1943, p. 72); size 28μ .
- Triorites* (*Lythracidites*) spm. (Pl. XIV, fig. 23A; text-fig. 24).—Grain triorate, triangular, germinal pores outstanding; texture of the grain psilate; polar view, 22.5μ . Such type of grains are also found in the longitudinal section of the flower, *Sahnianthus*, which is shown to have a Lythraceous affinity. (Pl. XIV, fig. 23B).
- Porites* spm. (Pl. XIV, fig. 24).—Grains spheroidal, porate with a great sculpturing of ridges and lacunae; the ridges are without spines; size 92μ . These grains show much resemblance to those of *Barnadesia* in the tribe Mutisieae from the Compositae family, (Wodehouse 1935², p. 468).

OTHER ORGANIC MICRO-REMAINS.

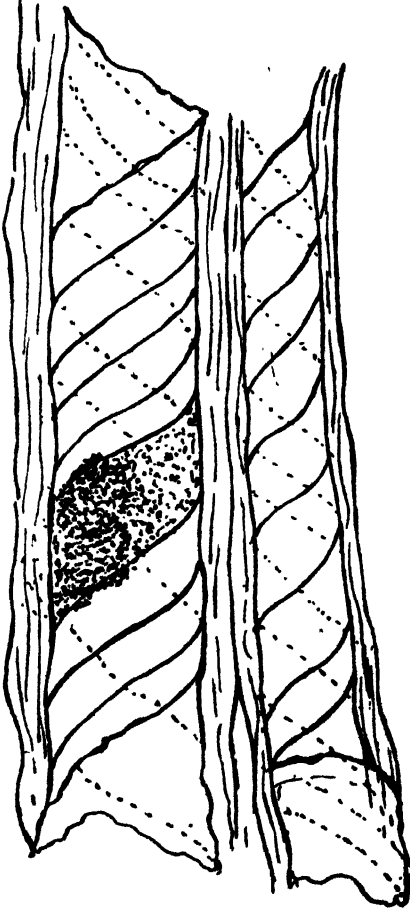
Plant Cuticles.

Fragments of cuticles are abundant, but two of them are found to be quite illustrative. One of them is a small piece of cuticle, possibly of dicotyledonous or gymnospermic leaves, cells short, with slightly sinuous walls; stomata absent; (Pl. XIV, fig. 25; text-fig. 25).

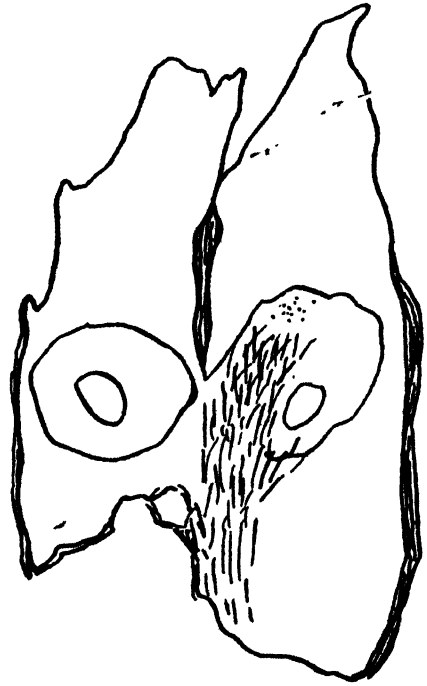
The other piece of cuticle belongs to a leaf, with well-preserved stomata; the cells are elongated and with sinuous walls; stomata are dumbbell-shaped. This character of the dumbbell-shaped stomata (Pl. XIV, fig. 26) with the sinuous walled, elongated cells implies the resemblance of this type of cuticle to that of a Gramineae. (Pls. XIV and XV, figs. 26 and 27).

EPIDERMAL OUTGROWTHS.

Epidermal outgrowths are found in the form of many hairs of different lengths and different types. (Pl. XV, fig. 28). Some of them are also found to be attached to cuticles. (Pl. XV, fig. 27.) Out of all these one is found to be rather interesting in that it is unicellular with a pointed apex. (Pl. XV, fig. 29; text-fig. 26).



27



28

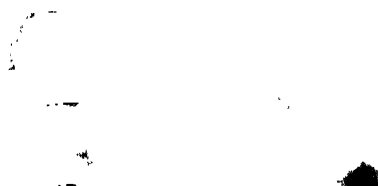
Fig. 27. A bit of vascular elements with spiral thickening on walls. \times Ca. 1200.
 Fig. 28. A bit of vascular elements with bordered pits on the walls. \times Ca. 1200.

VASCULAR ELEMENTS.

A bit of two vascular elements with spiral thickening on the walls (Pl. XV, fig. 30; text-fig. 27). Another bit of two vascular elements with bordered pits on the radial walls. The pore of the pit is oblique (Pl. XV, fig. 31, text-fig. 28).



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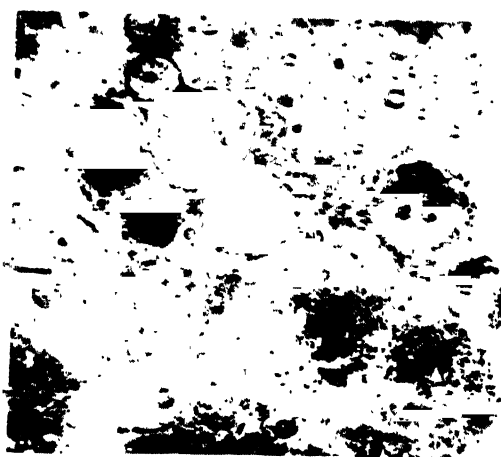


23A



23B

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DISCUSSION.

In India, the Tertiary microflora has not been worked out thoroughly. The Tertiary microflora of the Madhya Pradesh particularly is practically untouched. This paper deals with the description for the first time of the microflora from the Mohgaon-Kalan beds. The age of the beds is no doubt Tertiary (Sahni 1934, Sahni and Rode 1937), and according to the late Prof. Sahni (1940), it is early Tertiary and most probably Eocene. The present observations on the microflora so far, have been found to support this view. Some of the tricolpate pollen grains described in this paper resemble those of Lythraceae, Myrtaceae, Rosaceae, Rhamnaceae, Betulaceae, and Compositae; also pollen grains similar to those of Gramineae, Palmae, and Typhaceae have been observed. From the same bed palm stems and roots were described previously by Rode (1933), *Enigmocarpon* fruits by Sahni (1943), and *Sahnianthus*, a flower genus, by Shukla (1944). The last two have Lythraceous affinities. A dicotyledonous wood had been discovered from the same bed by Rode in 1936. Hence one should not be at all surprised if the pollen grains belonging to the megafloora already described are obtained during the investigation of the microflora of the same bed. The abundance of the angiospermic pollen grains as also the occurrence of a leaf cuticle with dumbell-shaped stomata is notable. From this it can be confidently suggested that further investigation of the microflora from these beds and its correlation with that of the other beds of Eocene age, will show that the Intertrappean series exposed near Mohgaon-Kalan are most probably of Eocene age.

ACKNOWLEDGMENTS.

The author wishes to express her sincere gratitude to Dr. (Mrs.) Chinna Jacob and Dr. K. Jacob for many helpful suggestions. She also expresses her grateful thanks to Dr. W. D. West, Director of the G.S.I., Calcutta, for permitting her to work in the Palaeobotanical Department for a few days and to use the library.

SUMMARY.

This paper deals with the fossil Microflora from the Tertiary beds of the Madhya Pradesh, exposed near village Mohgaon-Kalan in the Chhindwara district.

Description of twenty-six different kinds of spores and pollen grains is given in the first part of the paper. Out of these, five types of spores belong to pteridophytes, two to gymnosperms, and the rest to angiosperms.

In the next part, are recorded two types of vascular elements, one with bordered pits on the wall, and another with spiral thickening; a unicellular hair with pointed end; a piece of leaf cuticle with short sinuous walled cells; another piece of cuticle probably of Gramineae, with sinuous walled, elongated cells and dumbell-shaped stomata; and a few epidermal outgrowths of unicellular pointed hairs.

Pollen grains showing the closest resemblance to those of Lythraceae, Myrtaceae, Palmaceae, Rosaceae, etc. are identified and it is suggested that further investigation of the microflora from these beds will in all probability corroborate the late Prof. Sahni's view that they are of Eocene age.

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- (1935)² Pollen grains.

EXPLANATION OF PLATES.

All the figures are from untouched negatives. Unless otherwise specified all are of microfossils isolated from the Tertiary cherts of the Mohgaon-Kalan beds. The magnification for all is 700 unless otherwise specified.

PLATE XIII.

- FIG. 1. *Alites* spm.—A pteridophytic spore.
- FIG. 2. *Monolites* spm.—Bean shaped.
- FIG. 3. *Trilites* spm.—A pteridophytic spore.
- FIG. 4. *Trilites* spm.—Tetrad scar prominent extending to the periphery.
- FIG. 5. *Trilites* spm.—Tetrad mark prominent.
- FIG. 6. *Monosaccites* spm.—Gymnospermic grain with one wing.
- FIG. 7. *Disaccites* spm.—Gymnospermic grain with two wings.
- FIG. 8. *Tetrado-Monosporites* (*Typhidites*) spm.—Three grains united together. Each with a pore.
- FIG. 9. *Monosulcites* (*Palmidites*) *minima*.—A preparation from a peel section.
- FIG. 10. *Monosulcites* (*Palmidites*) *media*.—Lateral view of the grain. A preparation from a peel section.
- FIG. 11. *Monosulcites* (*Palmidites*) *spinosa*.—A preparation from a peel section.
- FIG. 12. *Monosulcites* spm.
- FIG. 13A. *Tricolpites* (*Rhamnacidites*) spm.—Polar view.
- FIG. 13B. *Tricolpites* spm.—Slightly oblique view.
- FIG. 14. *Tricolpites* spm.—Polar view.
- FIG. 15. *Tricolporites* (*Myrtacidites*) sp.—Polar view.

PLATE XIV.

- FIG. 16. *Tricolporites* spm.—Polar view.
 FIG. 17. *Tricolporites* spm.—Polar view.
 FIG. 18. *Tricolporites* (*Rosacidites*) spm.—Equatorial view.
 FIG. 19. *Tricolporites* (*Rosacidites*) spm.—Equatorial view. Germinal Pores distinct.
 FIG. 20. *Tricolporites* spm.—Equatorial view.
 FIG. 21. *Priorites* (*Betulacidites*) spm.—Three germinal pores bulging out.
 FIG. 22. *Priorites* (*Betulacidites*) spm.—Exine reticulate.
 FIG. 23A. *Priorites* (*Lythracidites*) spm.—
 FIG. 23B. Pollen grains from an anther lobe of *Sahnianthus*. $\times 225$.
 FIG. 24. *Porites* spm.—Photo from a section prepared. $\times 140$.
 FIG. 25. A piece of cuticle; cells with short and sinuous walls.
 FIG. 26. An enlargement of a part from the fig. 27, Pl. III, showing dumbbell-shaped stomata.

PLATE XV.

- FIG. 27. A piece of cuticle with epidermal outgrowths attached; cells elongated, with sinuous walls. $\times 120$.
 FIGS. 28 and 29. Epidermal outgrowths.
 FIG. 30. A piece of vascular elements with spiral thickening on the walls.
 FIG. 31. A bit of two vascular elements with bordered pits on the radial walls.

THE NEAR ULTRAVIOLET ABSORPTION SPECTRUM OF PSEUDO-CUMENE.

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(Communicated by Prof. K. Rangadhama Rao, F.N.I.)

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INTRODUCTION.

Among the electronic transitions in trisubstituted benzenes an extensive study has been made only* in the case of the trichlorobenzenes by Sponer (1947) who investigated their absorption spectra in the vapour state. Investigations of many other molecules of this type were made mostly in solutions but such solution spectra give us the gross features of the spectrum merely and determination of the absorption coefficients in solutions indicate the character of the transition in question namely whether it is allowed or forbidden. For obtaining a knowledge of the vibrations of the molecule more completely a study of the absorption spectra in the vapour state is essential. With this object in view, an investigation of the absorption spectra of trimethyl benzenes is undertaken. This paper gives the results obtained for the 1 : 2 : 4 isomer.

The Raman spectrum of this molecule was studied by Kohlrausch and Pongratz (Magat, 1936) who reported a number of vibrational frequencies in the ground state. Conrad-Billroth (1935) studied its absorption in hexane solution, (the molar concentration amounting to 7×10^4). Reference may be made to this paper for earlier work. Conrad-Billroth reported three regions of absorption at 36250, 37300 and 38300 and represented the absorption intensities by a curve.

EXPERIMENTAL.

The experimental arrangement used in this investigation was described elsewhere (Sreeramamurty, 1950). The substance was from a Kahlbaum sample, the purity of which was tested prior to the absorption experiments by a determination of its boiling point and refractive index (using an Abbe refractometer). The spectrum obtained, using a synthetic sample prepared according to the procedure of Smith and Lund (1930) confirmed the purity. In the vapour state spectra at different temperatures were obtained varying from -15°C . to 40°C . Plate I is a reproduction of the absorption under different conditions. As seen from the reproduction the absorption bands in the vapour state are line-like and sharp. There is but a very slight degradation to the red and no band at all is degraded to the violet. As observed in several other spectra the bands develop a diffuse character in the region of shorter wavelengths from about $\lambda 2610$. Throughout the entire range of the spectrum there appears to exist a slight background of continuous absorption. Accompanying each strong band a number of individual bands occur as usual in these spectra. In all these features the spectrum resembles that of 1 : 2 : 4 trichlorobenzene. About 75 bands have altogether been measured extending from $\lambda 2796$ to $\lambda 2470$. The spectrum extends considerably also towards the red of the 0, 0 band.

ANALYSIS AND DISCUSSION.

If the methyl groups are assumed as 'single atoms', as a first approximation, the characteristic features of the electronic absorption systems of trimethylbenzenes may be considered to be closely analogous to the corresponding trichlorobenzenes. For the latter, Sponer has shown that the symmetrical 1 : 3 : 5 substitution gives rise to an electronic transition $A_1' - A_2'$ corresponding to the trigonal group D_{3h} . As in benzene this transition is forbidden. But when an unsymmetrical vibration of type ϵ' is singly excited with the electronic transition, the transition is made allowed and the spectrum will appear with weak intensity. The 1 : 2 : 3 isomer corresponds to the symmetry C_{2v} and its near ultraviolet absorption represents the $A_1 - B_1$ transition. Although this transition is allowed, as Sklar has calculated, the spectrum will appear through only a vibrational moment. The 1 : 2 : 4 substitution has the lowest symmetry, viz., C_s among the substituted benzenes, unless the symmetry is further reduced by the CH_3 radical not behaving as a 'single atom'. The transition is represented by $A' - A'$; it is an allowed one, giving rise to a strong 0, 0 band. The vapour spectrum distinctly indicates $\nu 36900$ as the strongest in the group of bands appearing in the region of longer wavelengths. This must be assumed as the 0, 0 transition. To the red of the 0, 0 band the spectrum extends up to a wavenumber interval of about 1150 cm^{-1} . Among these bands seven of the frequencies observed by Kohlrausch and Pongratz in the Raman spectrum have been identified ranging from 217 to 1151. Three bands, however, stand out among the stronger ones which could not be assigned as belonging to any combination. In the complex group close to $\nu 36900$ two frequencies 25 and 45 occur frequently. Several independent small vibrations may be involved in the emission of these bands.

To the violet side of the group containing the 0, 0 band, the spectrum shows about four clear groups. The first contains the upper state frequency 711. The second and third have led to the frequencies 927, 1180 and 1286. Very probably 927 and 1180 represent the symmetric carbon ring vibrations. The doubly and trebly excited combinations of these are no doubt detected but the absence of these may be due to the general fall in intensity and the diffuseness of the bands in the region of smaller wavelengths. Although progressions are absent the frequencies mentioned above occur in several combinations and, hence, may represent the characteristic values of the upper state. The difference frequencies 25 and 45 occur several times in combination with these frequencies. The 927 band is much more intense than 1180. It is comparable in intensity to 711.

In toluene (monomethyl substitution) the vibration of frequency 785 cm^{-1} in ultraviolet absorption is correlated with the totally symmetric $\text{C}-\text{CH}_3$ bond vibration in the ground state in analogy with 808 in fluorobenzene (Bass, 1950). The corresponding upper state frequency is suggested as 751 cm^{-1} . In the xylenes, *p*, *m*, *o* the frequencies 720, 724, 740 respectively are assigned to the $\text{C}-\text{CH}_3$ vibration in the ground state by Pitzer and Scott (1943). A comparison of these frequencies with the $\text{C}-\text{Cl}$ vibrations in mono- and trichloro substitutions suggests the assignment of the strong totally symmetrical vibration 711 in this trimethyl molecule as corresponding to the $\text{C}-\text{CH}_3$ valence vibration in the upper state. It is to be associated with 744 in the Raman frequencies. Table I gives the correlation, between the ground and upper state frequencies suggested from the present data.

ABSORPTION SPECTRUM OF PSEUDO-CUMENE

TABLE I.

Ground state.		Excited state.
Raman, Kohrausch and Pongratz.	U.V. abs. Author.	Author.
210 (4)	217 mw	115 m
285 (2)	289 mw	
321 (6)	328 mw	
432 (6)		
474 (5)		
557 (8)	549 vvw	711 st
715 (5)		
744 (8)		
807 (8)		
928 (3)	923 vvw	927 mst
1125 (2)	1128 vw	
1150 (1)	1151 vvw	1180 m 1180 m 1286 mw
1205 (0.5)		
1239 (10)		
1377 (10)		
1444 (5)		

Table II gives the complete measurements on the band heads together with their assignments. Bands bracketed in the table may represent close doublets. Such doublet structure was reported earlier in fluorobenzene, aniline and phenol.

TABLE II.

Wavelength.	Wavenumber.	Int.	Difference from 0, 0.	Assignment.
2796.43	35749	vw	1151	0-1151
94.67	772	vw	1128	0-1128
93.49	787	w	1113	
90.20	829	mw	1071	
89.95	832	m	1068	
86.20	881	mw	1019	
85.78	886	m	1014	0-1128-115
85.36	891	mst	1009	
82.99	922	vw	978	0-923-45
81.15	946	m	954	
80.86	950	mst	950	0-923-25
78.75	977	vw	923	0-923
74.21	36036	w	864	
50.06	351	vw	549	0-549
49.28	362	w	538	
43.33	441	vw	459	0-549+85
39.51	492	w	408	
38.44	510	mw	390	
36.64	530	vw	370	0-328-45
33.54	572	mw	328	0-328
30.63	611	mw	289	0-289
27.42	654	mst	246	0-328+85
25.28	683	mw	217	0-217
23.51	707	mw	193	}
23.05	713	w	187	
21.82	729	mw	171	
20.06	753	mw	153	
19.83	756	m	144	0-217+115-45
18.90	769	mw	131	
17.63	786	w	114	
16.05	807	mw	93	0-2x45

TABLE II—(Contd.)

Wavelength.	Wavenumber.	Int.	Difference from 0, 0	Assignment.*
2715.73	812	mw	88	
14.51	828	m	72	
12.86	851	mst	49	0-2×25
12.52	855	st	45	0-45
11.38	871	st	29	0-807+777
11.05	875	st	25	0-25
09.43	896	vst	4	
09.20	900	vvst	0	0, 0
06.99	930	mst	30	
06.40	939	w	39	
06.17	942	mst	42	
04.49	965	mw	65	0+115-2×25
04.10	970	mw	70	0+115-45
03.02	985	m	85	0+115-25
01.77	37002	mw	102	
00.99	012	m	112	
00.78	015	m	115	0+115
2698.39	048	vvw	148	
90.50	157	vvw	257	
81.25	285	w	385	0-328+711
70.99	428	vvw	528	
68.00	470	m	570	
65.97	499	vvw	599	0-328+927
64.15	524	mw	624	
62.93	542	mw	642	0+711-45-25
661.71	7559	w	659	0+711-2×25
61.17	566	mw	666	0+711-45
60.61	574	w	674	
59.57	588	m	688	0+711-25
58.00	611	st	711	0+711
55.17	651	w	751	
54.33	663	m	763	
52.96	683	mw	783	
49.13	737	w	837	0+927-2×45
48.02	753	w	853	0+927-45-25
				0-328+1180
45.78	785	mw	885	0+927-45
44.44	804	mw	904	0+927-25
43.02	824	mw	924	
42.82	827	mst	927	0+927
37.07	900	vvw	1000	0+927+115-45
34.61	945	w	1045	0+927+115
30.30	38007	mw	1107	0+1180-45-25
28.83	028	mw	1128	0+1180-45
26.89	056	m	1156	0+1180-25
25.29	080	mw	1180	0+1180
23.76	102	mw	1202	0+1286-45-25
21.15	140	mw	1240	0+1286-45
19.83	159	mw	1259	0+1286-25
17.97	186	mw	1286	0+1286
17.66	191	w	1291	0+1180+115
10.63	294	mw	1394	0+1286+115
2596.72	499	w	1599	0+927+711-45
94.03	539	mw	1639	0+927+711
92.91	555	vvw	1655	
89.37	608	mw	1708	
88.85	616	mw	1716	
86.00	658	mw	1758	
84.45	682	vvw	1782	
63.06	39004	w	2104	0+1180+927
61.46	029	mw	2123	
60.38	045	vw	2145	
28.89	531	w	2631	

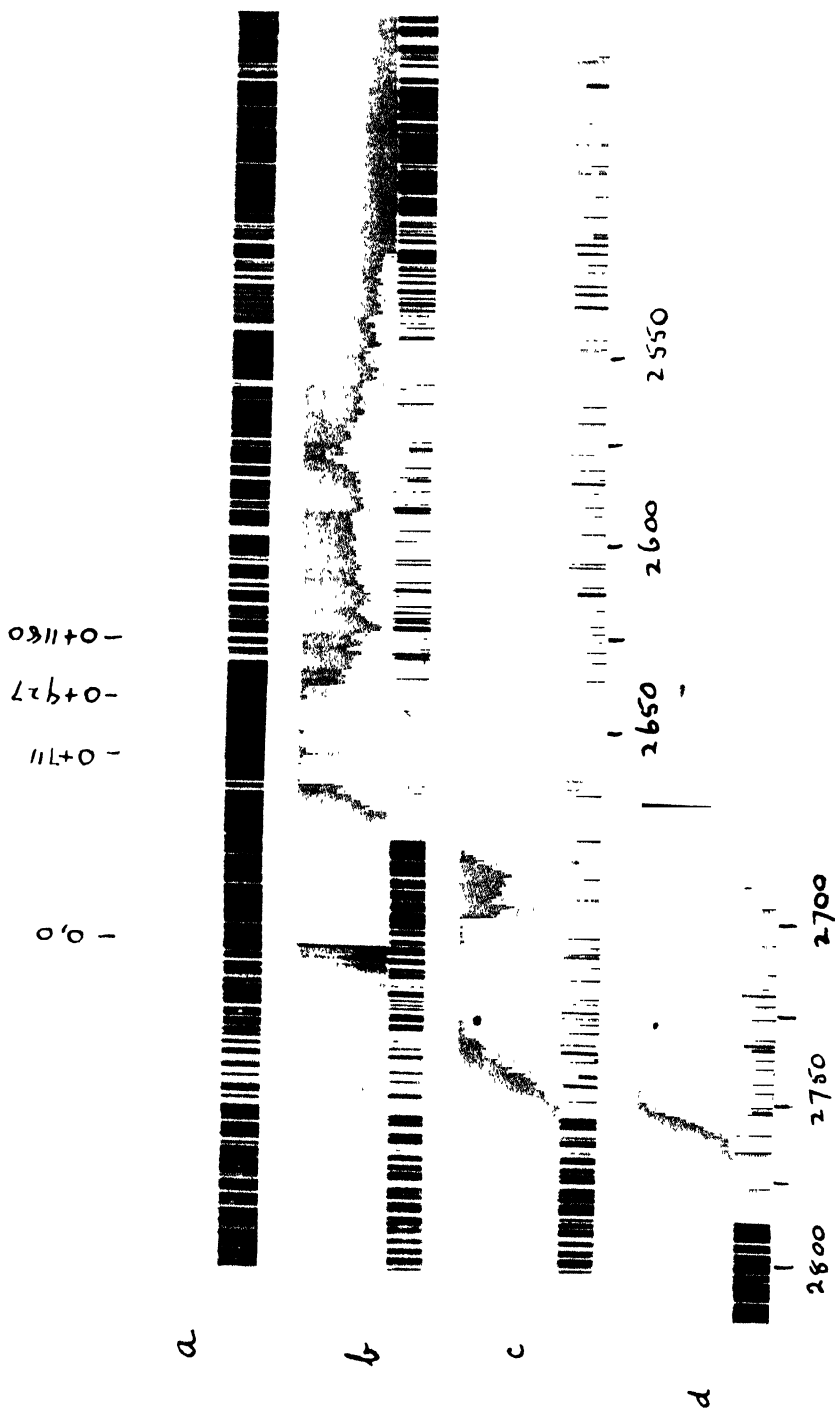
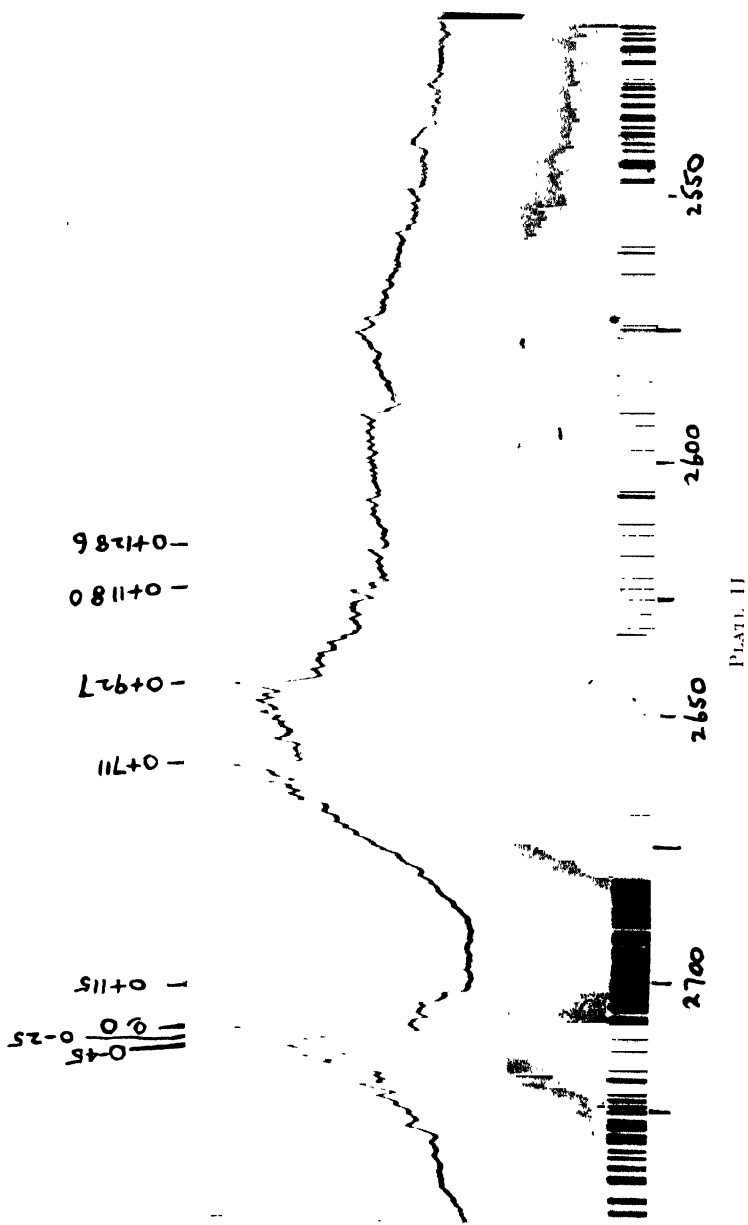


PLATE I. Development of the spectrum of 1 : 2 : 4 trimethyl benzene under different experimental conditions.
a. 25 cms, at -15°C . *b.* 50 cms, at 10°C . *c.* 75 cms, at 28°C . *d.* 75 cms, at 40°C .



SUMMARY.

The absorption spectrum of pseudo-cumene in the vapour phase was studied in the region 2800 to 2725. The electronic transition is $A'-A'$ and represents an allowed one. Five upper state frequencies 115, 711, 927, 1180 and 1286 and two difference frequencies 25 and 45 have been established. Several ground state frequencies have been observed to the red of the 0, 0 band at 36900 and were compared with the Raman frequencies. An assignment of the frequencies has been discussed.

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EQUILIBRIUM OF ROTATING FLUIDS UNDER THE QUADRATIC LAW OF STRATIFICATIONS AND THE EXISTENCE OF EQUATORIAL ACCL.

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INTRODUCTION.

It has been observed that in the sun (as also in Saturn and Jupiter) the parts nearer the equatorial plane on the surface move faster than those nearer the pole (Adams, W. S., 1911). This has been found to be true of some of the rotating nebulae also. H. Faye (1865) attempted an explanation of this phenomenon in the sun by the assumption of radial convection currents caused by the surface-cooling of the sun. All hydrodynamical models of perfect fluids under axial rotation, constructed so far, have shown however just the opposite effect (namely equatorial retardation), if not a constant angular velocity on the surface. Maclaurin's spheroids have uniform density and uniform rotation. The heterogeneous models whose existence was proved by Dive and very recently discussed by the author are also cases showing the same behaviour (Dive, 1930; Ghosh, 1950 A, B). In the present paper some specimens of fluid models have been constructed that exhibit 'equatorial acceleration' on the surface. The fluid body has variable density and is in equilibrium under self-gravitation only, in a state of pure rotation, with variable angular-velocity.

The law of density stratifications in the rotating models is assumed to be given by

$$\rho = \rho_0(1 - \lambda \alpha r^2 - \mu \beta z^2) \quad \dots \quad (1)$$

the boundary of the fluid being

$$1 - \alpha r^2 - \beta z^2 = 0 \quad \dots \quad (2)$$

and where r and z are the cylindrical co-ordinates of any point in the fluid and α, β the reciprocals of the squares of the semi-axes of the boundary spheroid.

SEC. 1a. THE GRAVITATIONAL POTENTIAL.

1. By an adaptation of Dyson's formula for the potential of a heterogeneous ellipsoid (Routh, *Statics*, Vol. II, Art. 247, p. 125), for the distribution (1) and the boundary (2), the potential V in cylindrical co-ordinates, at an internal point (r, z) is easily obtained as,

$$V(r, z) = \pi \rho_0 a^2 c \int_0^\infty \frac{d\theta}{(\alpha^2 + \theta)(c^2 + \theta)^{\frac{3}{2}}} \left(1 - \frac{r^2}{\alpha^2 + \theta} - \frac{z^2}{c^2 + \theta} \right) \left[\left\{ 1 - \frac{\lambda \alpha^2 r^2}{(\alpha^2 + \theta)^2} - \frac{\mu c^2 z^2}{(c^2 + \theta)^2} \right\} \right. \\ \left. - \frac{\theta}{4} \left\{ \frac{2\lambda}{\alpha^2 + \theta} + \frac{\mu}{c^2 + \theta} \right\} \times \left\{ 1 - \frac{r^2}{\alpha^2 + \theta} - \frac{z^2}{c^2 + \theta} \right\} \right].$$

putting

$$\left. \begin{aligned} \frac{\partial V}{\partial r^2} &= C [L + Mr^2 + Nz^2] \\ \frac{\partial V}{\partial z^2} &= C' [L' + M'r^2 + N'z^2] \end{aligned} \right\} \dots \dots \dots (1.1)$$

where

$$C' = \pi \rho_0 a^2 c \dots \dots \dots (1.2)$$

we have

$$L = - \int_0^\infty \frac{d\theta}{(a^2 + \theta)^2 (c^2 + \theta)^{\frac{1}{2}}} \left\{ 1 + \lambda \cdot \frac{a^2 - \theta}{a^2 + \theta} - \frac{1}{2} \mu \cdot \frac{\theta}{c^2 + \theta} \right\} \dots (1.3a)$$

$$M = \int_0^\infty \frac{d\theta}{(a^2 + \theta)^2 (c^2 + \theta)^{\frac{1}{2}}} \left\{ \lambda \cdot \frac{2c^2 - \theta}{a^2 + \theta} - \frac{1}{2} \mu \cdot \frac{\theta}{c^2 + \theta} \right\} \dots (1.3b)$$

$$N = \int_0^\infty \frac{d\theta}{(a^2 + \theta)^2 (c^2 + \theta)^{\frac{1}{2}}} \left\{ \lambda \cdot \frac{a^2 - \theta}{a^2 + \theta} + \frac{1}{2} \mu \cdot \frac{2c^2 - \theta}{c^2 + \theta} \right\} \dots (1.3c)$$

$$L' = - \int_0^\infty \frac{d\theta}{(a^2 + \theta)(c^2 + \theta)^{\frac{3}{2}}} \left\{ 1 - \lambda \cdot \frac{\theta}{a^2 + \theta} + \frac{1}{2} \mu \cdot \frac{2c^2 - \theta}{c^2 + \theta} \right\} \dots (1.3d)$$

$$M' = N = \int_0^\infty \frac{d\theta}{(a^2 + \theta)^2 (c^2 + \theta)^{\frac{3}{2}}} \left\{ \lambda \cdot \frac{a^2 - \theta}{a^2 + \theta} + \frac{1}{2} \mu \cdot \frac{2c^2 - \theta}{c^2 + \theta} \right\} \dots (1.3e)$$

$$N' = \int_0^\infty \frac{d\theta}{(a^2 + \theta)(c^2 + \theta)^{\frac{3}{2}}} \left\{ -\lambda \cdot \frac{\theta}{a^2 + \theta} + \frac{1}{2} \mu \cdot \frac{4c^2 - \theta}{c^2 + \theta} \right\} \dots (1.3f)$$

Putting

$$\left. \begin{aligned} L &= L_0 + \lambda L_1 + \mu L_2; \quad M = \lambda M_1 + \mu M_2; \quad N = \lambda N_1 + \mu N_2; \\ L' &= L'_0 + \lambda L'_1 + \mu L'_2; \quad M' = \lambda M'_1 + \mu M'_2; \quad N' = \lambda N'_1 + \mu N'_2; \end{aligned} \right\} \dots (1.4)$$

and using the notation

$$\int_0^\infty \frac{f(\theta) \cdot d\theta}{(a^2 + \theta)^m (c^2 + \theta)^n} = [f(\theta)]_{m, n} \dots \dots \dots (1.5)$$

we have

$$\begin{aligned} L_0 &= - \left[\frac{1}{2, \frac{1}{2}} \right]; \quad L_1 = - \left[\frac{a^2 - \theta}{3, \frac{1}{2}} \right]; \quad L_2 = \frac{1}{2} \left[\frac{\theta}{2, \frac{3}{2}} \right]; \\ M_1 &= \left[\frac{2a^2 - \theta}{4, \frac{1}{2}} \right]; \quad M_2 = -\frac{1}{2} \left[\frac{\theta}{3, \frac{3}{2}} \right]; \\ N_1 &= \left[\frac{a^2 - \theta}{3, \frac{3}{2}} \right]; \quad N_2 = \frac{1}{2} \left[\frac{2c^2 - \theta}{2, \frac{5}{2}} \right]; \\ L'_0 &= - \left[\frac{1}{1, \frac{3}{2}} \right]; \quad L'_1 = \left[\frac{\theta}{2, \frac{3}{2}} \right]; \quad L'_2 = -\frac{1}{2} \left[\frac{2c^2 - \theta}{1, \frac{5}{2}} \right]; \\ M'_1 &= \left[\frac{a^2 - \theta}{3, \frac{3}{2}} \right]; \quad M'_2 = \frac{1}{2} \left[\frac{2c^2 - \theta}{2, \frac{5}{2}} \right]; \\ N'_1 &= - \left[\frac{\theta}{2, \frac{5}{2}} \right]; \quad N'_2 = \frac{1}{2} \left[\frac{4c^2 - \theta}{1, \frac{7}{2}} \right]. \dots \dots \dots (1.6) \end{aligned}$$

2. It will be useful, for later reference, to note here that the coefficients L , M , N , etc. are not independent. By considering Poisson's equation we can at once show that

$$2L + L' = -2/a^2c; \quad 4M + M' = 2\lambda/a^4c; \quad 2N + 3N' = 2\mu/a^2c^3;$$

which by (1.4) lead to

$$\left. \begin{aligned} 2L_0 + L'_0 &= -2/a^2c; & 2L_1 + L'_1 &= 0; & 2L_2 + L'_2 &= 0; & 4M_1 + M'_1 &= 2/a^4c; \\ 4M_2 + M'_2 &= 0; & 2N_1 + 3N'_1 &= 0; & 2N_2 + 3N'_2 &= 2/a^2c; \end{aligned} \right\} \quad (1.7)$$

Also considering that $\frac{\partial^2 V}{\partial r^2 \partial z^2} = \frac{\partial^2 V}{\partial z^2 \partial r^2}$ we have $M'_1 = N_1$; $M'_2 = N_2$ as is obvious from (1.6).

From (1.7) and (1.6), we can at once show that

$$\left. \begin{aligned} \left[\begin{array}{c} 2c^2 - \theta \\ 1, \frac{1}{2} \end{array} \right] &= 2 \left[\begin{array}{c} \theta \\ 2, \frac{3}{2} \end{array} \right] \\ \left[\begin{array}{c} a^2 - \theta \\ 3, \frac{1}{2} \end{array} \right] &= \frac{1}{2} \left[\begin{array}{c} \theta \\ 2, \frac{3}{2} \end{array} \right] \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (1.8)$$

Hence, both the quantities on the left-hand-side of (1.8) are positive. This information will be utilised later on.

SEC. 1b. EQUILIBRIUM IN PLANE STRATIFICATIONS.

The general case corresponding to the density stratification (1) leads to complicated calculations. To get an insight into our problem we shall first discuss a special case of (1) for $\lambda = 0$ and assume the law of density stratification to be given by

$$\rho = \rho_0(1 - \mu\beta z^2) \quad \dots \quad \dots \quad \dots \quad (1.9)$$

for

$$0 < \mu < 1 \quad \dots \quad \dots \quad \dots \quad \dots \quad (1.9a)$$

where, of course,

$$\alpha = \frac{1}{a^2} \quad \text{and} \quad \beta = \frac{1}{c^2} \quad \dots \quad \dots \quad \dots \quad \dots \quad (1.9b)$$

The equations of motion for steady rotation of a perfect fluid, in cylindrical co-ordinates (r, z) , are given by

$$\left. \begin{aligned} \frac{\omega^2}{2} &= -\frac{\partial V}{\partial r^2} + \frac{1}{\rho} \frac{\partial p}{\partial r^2} \\ 0 &= -\frac{\partial V}{\partial z^2} + \frac{1}{\rho} \frac{\partial p}{\partial z^2} \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad \dots \quad (1.10)$$

where ω , V , p , ρ represent respectively, the angular velocity, the gravitational potential, the pressure and the density.

For the density-distribution (1.9), the values of $\frac{\partial V}{\partial r^2}$, $\frac{\partial V}{\partial z^2}$ can be at once obtained from (1.3) by putting $\lambda = 0$. We shall take them to be represented by (1.1) in general,

Now, from (1.10) we find, by eliminating p ,

$$\frac{\partial}{\partial z^2} \left(\frac{\rho \omega^2}{2} \right) = \rho_0 \mu \beta \frac{\partial V}{\partial r^2} \quad \dots \quad (1.11)$$

Hence, substituting from (1.1) and integrating partially we have

$$\frac{1}{2} \rho \omega^2 = \rho_0 \left[\mu \beta L z^2 + \mu \beta M r^2 z^2 + \frac{1}{2} \mu \beta N z^4 \right] + F(r^2) \quad \dots \quad (1.12)$$

where $F(r^2)$ stands for any arbitrary function of r^2 .

Now, we see that $\frac{\partial V}{\partial r^2}$ and $\frac{\partial V}{\partial z^2}$ are both quadratic functions of r and z and so is also ρ ; hence the derivatives of the pressure appearing in (1.10) are not expected to be of a degree higher than 4 at least in z , and the same remark applies to $\rho \omega^2$. So we may assume that the pressure, in general, is of degree 6 and $\rho \omega^2$ contains no power of r higher than r^4 . Therefore, we put

$$F(r^2) = \rho_0 \left[K_0 + K_1 r^2 + K_2 r^4 \right] \quad \dots \quad (1.13)$$

and

$$p = \rho_0 (1 - \alpha r^2 - \beta z^2) \left\{ A_0 + A_1 \alpha r^2 + A_2 \beta z^2 + A_3 \alpha \beta r^2 z^2 + A_4 \alpha^2 r^4 + A_5 \beta^2 z^4 \right\} \quad \dots \quad (1.14)$$

the first factor on the right making the pressure vanish on the boundary (2).

With these we have, from (1.12), (1.1) and (1.14)

$$\frac{\rho \omega^2}{2} = \rho_0 \left[K_0 + K_1 r^2 + \mu \beta L z^2 + \mu \beta M r^2 z^2 + K_2 r^4 + \frac{1}{2} \mu \beta N z^4 \right] \quad \dots \quad (1.15)$$

$$\left. \begin{aligned} \frac{1}{\rho_0} \left\{ \rho \frac{\partial V}{\partial r^2} + \frac{\rho \omega^2}{2} \right\} &= (K_0 + L) + (K_1 + M) r^2 + M' z^2 + K_2 r^4 - \frac{1}{2} \mu \beta N z^4 \\ \frac{1}{\rho_0} \cdot \rho \cdot \frac{\partial V}{\partial z^2} &= L' + M' r^2 + (N' - \mu \beta L') z^2 - \mu \beta M' r^2 z^2 - \mu \beta N z^4 \\ \frac{1}{\rho_0} \cdot \frac{\partial \rho}{\partial r^2} &= \alpha \left[(A_1 - A_0) + 2(A_4 - A_1) \alpha r^2 + (A_3 - A_1 - A_2) \beta z^2 \right. \\ &\quad \left. - 2(A_3 + A_4) \alpha \beta r^2 z^2 - 3A_4 \alpha^2 r^4 - (A_3 + A_5) \beta^2 z^4 \right] \\ \frac{1}{\rho_0} \cdot \frac{\partial \rho}{\partial z^2} &= \beta \left[(A_2 - A_0) + (A_3 - A_1 - A_2) \alpha r^2 + 2(A_5 - A_2) \beta z^2 \right. \\ &\quad \left. - 2(A_3 + A_5) \alpha \beta r^2 z^2 - (A_3 + A_4) \alpha^2 r^4 - 3A_5 \beta^2 z^4 \right] \end{aligned} \right\} \quad \dots \quad (1.15a)$$

Hence substituting in (1.10) and equating the coefficients of like terms on both sides we have, as the conditions for equilibrium under self-gravitation,

$$\left. \begin{aligned} \alpha(A_1 - A_0) &= K_0 + L \quad \dots (1) \\ 2\alpha^2(A_4 - A_1) &= K_1 + M \quad \dots (2) \\ \alpha\beta(A_3 - A_1 - A_2) &= M' \quad \dots (3) \\ 2\alpha^2\beta(A_3 + A_4) &= 0 \quad \dots (4) \\ -3\alpha^3 A_4 &= K_2 \quad \dots (5) \\ \alpha\beta^2(A_3 + A_5) &= \frac{1}{2} \mu \beta N \quad \dots (6) \end{aligned} \right\} \quad \left. \begin{aligned} \beta(A_2 - A_0) &= L' \quad \dots (7) \\ \alpha\beta(A_3 - A_1 - A_2) &= M' \quad \dots (8) \\ 2\beta^2(A_5 - A_2) &= N' - \mu \beta L' \quad \dots (9) \\ 2\alpha\beta^2(A_3 + A_5) &= \mu \beta M' \quad \dots (10) \\ \alpha^2\beta(A_3 + A_4) &= 0 \quad \dots (11) \\ 3\beta^3 A_5 &= \mu \beta N' \quad \dots (12) \end{aligned} \right\} \quad (1.16)$$

The twelve equations in (1.16) may be regarded as the conditions necessary for equilibrium under self-gravitation. But they are not all independent. Equations (3), (4) and (6) are exactly the same as (8), (11) and (10) respectively and the rest are independent. Hence, there are only 9 independent equations in (1.16). The number of unknown constants in our problem, viz., $K_0, K_1, K_2, A_0, A_1, A_2, A_3, A_4, A_5$, for a given law of distribution and a given boundary, is also exactly nine. Hence in general, it will always be possible to evaluate the unknown constants.

The solutions for the unknown quantities are as follows:—

$$\begin{aligned}
 2\beta^2 A_0 &= \frac{1}{3}(2\mu-3)N' + (\mu-2)\beta L' \\
 2\alpha\beta^2 A_1 &= \frac{1}{3}(3-4\mu)\alpha N' + (\mu-2)\beta M' - \mu\alpha\beta L' \\
 2\beta^2 A_2 &= \frac{1}{3}(2\mu-3)N' + \mu\beta L' \\
 2\alpha\beta^2 A_3 &= -\frac{2}{3}\mu\alpha N' + \mu\beta N \\
 2\alpha\beta^2 A_4 &= \frac{2}{3}\mu\alpha N' - \mu\beta N \\
 3\beta^2 A_5 &= \mu N' \\
 2\beta^2 K_0 &= -2\beta^2 L + 2\alpha(1-\mu)(\beta L' + N') + (\mu-2)\beta M' \\
 \beta^2 K_1 &= \alpha^2\beta\mu L' - \beta^2 M + \alpha^2 N'(2\mu-1) + 2(1-\mu)\alpha\beta N \\
 2\beta^2 K_2 &= 3\alpha^2\beta\mu N - 2\alpha^3\mu N' \\
 &\dots \dots \dots \dots \dots (1.17)
 \end{aligned}$$

4. THE SURFACE ANGULAR VELOCITY.

The value of $\frac{1}{2}\rho\omega^2$ at any point of the model is given by (1.15). On the surface (2), we have

$$\alpha r^2 = 1 - \beta z^2 \quad \dots \dots \dots (1.18)$$

Hence, for the surface angular velocity ω_s , we have from (1.15)

$$\frac{\rho_s \cdot \omega_s^2 \cdot \beta^2}{\rho_0 \cdot C} = \left[2\beta^2 K_0 + 2\mu\beta^3 L z^2 + \mu\beta^3 N z^4 + (1-\beta z^2) \left\{ \frac{2\beta^2 K_1}{\alpha} + \frac{2\mu\beta^3 M z^2}{\alpha} + \frac{2\beta^2 K_2}{\alpha^2} (1-\beta z^2) \right\} \right] \dots (1.19)$$

where ρ_s denotes the density at the point (r, z) on the surface, and the variables on the right have their appropriate surface values. Now substituting the values of $2\beta^2 K_0, 2\beta^2 K_1, 2\beta^2 K_2$, from (1.16), simplifying and factorising we have on the surface

$$\frac{\rho_s \cdot \omega_s^2 \cdot \beta^2}{\rho_0 \cdot C} = 2(1-\mu\beta z^2) \left[-\beta^2 L - \beta N + \alpha(\beta L' + N') + (1-\beta z^2) \left\{ -\frac{\beta^2}{\alpha} \cdot M - \alpha N' + 2\beta N \right\} \right] \dots (1.19a)$$

By (1.9) the first factor on the right-hand-side of the above equation is ρ_s . Hence as $\rho_s \neq 0$ the surface angular velocity ω_s is given by

$$\frac{1}{2}\omega_s^2 = \frac{C}{\beta^2} \left[-\beta^2 L - \beta N + \alpha(\beta L' + N') + (1-\beta z^2) \left\{ -\frac{\beta^2}{\alpha} \cdot M - \alpha N' + 2\beta N \right\} \right] \dots (1.20)$$

(The formula (1.20) also holds for $\mu \rightarrow 1$.)

From this, we have at once

$$\frac{1}{2}\omega^2 \text{ (pole)} = \frac{C}{\beta^2} [-\beta^2 L - \beta N + \alpha(\beta L' + N')] \quad \dots \quad (1.21)$$

$$\frac{1}{2}\omega^2 \text{ (equator)} = \frac{C}{\beta} [\alpha L' - \beta L + N - \beta/\alpha \cdot M] \quad \dots \quad (1.22)$$

5. THE EQUATORIAL ACCELERATION.

From (1.20), we have

$$\frac{d}{dz^2} (\frac{1}{2}\omega_s^2) = C[\beta/\alpha \cdot M + \alpha/\beta \cdot N' - 2N] \quad \dots \quad (1.23)$$

This expression being a constant, the variation of ω_s^2 must be monotonic. Further, substituting the values of M , N' , N from (1.4) and (1.6) after putting $\lambda = 0$ in them, we have, on simplification,

$$\frac{d}{dz^2} (\frac{1}{2}\omega_s^2) = -C\mu \left[\frac{2c^2}{a^2} \cdot (a^2 - c^2) \left[\frac{\theta}{2, \frac{1}{2}} \right] + \frac{(a^2 - c^2)^2}{2a^2 c^2} \left[\frac{\theta^3}{3, \frac{1}{2}} \right] \right] \quad \dots \quad (1.24)$$

For all oblate spheroids and for positive values of μ only, the right-hand-side in (1.24) is obviously negative and, hence, ω_s^2 must *diminish* with increasing z^2 or z . This shows conclusively that the surface angular velocity must, in all cases, be larger at the equator than away from it. In other words the model must always show what is technically called '*equatorial acceleration*'.

6. THE CONDITIONS FOR THE REALITY OF THE SOLUTIONS.

We have not yet proved that the solutions given by (1.17) represent any real case. For this we have to show that

- (i) the pressure is everywhere positive inside;
- (ii) the density is nowhere negative;
- (iii) the square of the angular velocity is nowhere negative.

The first of these conditions has already been secured. For the pressure has been so chosen as to vanish on the surface and because it satisfies the second of equations (1.10) it must diminish outwards along any line parallel to the axis. This argument, due essentially to Dive, shows that it must be positive everywhere inside.

For (ii), we note that for all values of μ satisfying (1.9a), the density given by (1.9) must necessarily be positive everywhere inside. With density everywhere positive we notice that ω^2 will nowhere be negative unless $\rho\omega^2$ becomes negative.

From (1.11), however, it is clear that since $\frac{\partial V}{\partial r^2}$, representing the attraction component, must be negative, $\rho\omega^2$ must continuously diminish outwards along a parallel to the axis of rotation, barring the special case when $\mu = 0$ and the model reduces to the homogeneous Maclaurin's spheroid, the angular velocity being then constant everywhere. Hence, if $\rho\omega^2$ is nowhere negative on the outer surface it must be positive everywhere inside. Again, as the density does not vanish on the surface in the stratifications considered (except at the pole, for $\mu = 1$) $\rho\omega^2$ will be positive on the surface wherever ω^2 is positive. Thus a non-negative value of ω^2 everywhere on the surface ensures that ω^2 will not be negative anywhere inside.

Now, owing to monotonic decrease of ω^2 along a meridian section of the surface from the equator to the pole, the lowest value of ω^2 will be attained at the pole, and

hence it will be enough for any real case to have this lowest value non-negative. Thus, the necessary and sufficient condition for the reality of such models is

$$\omega^2(\text{pole}) > 0 \quad \dots \quad (1.25)$$

Hence, for all real cases of equilibrium in plane stratifications (1.9), we must have

$$-\beta^2 L - \beta N + \alpha(\beta L' + N') > 0 \quad \dots \quad (1.26)$$

from (1.21).

Now substituting from (1.4) for L , N , etc., in the case $\lambda = 0$, (1.26) becomes

$$(\alpha\beta L'_0 - \beta^2 L_0) + \mu \{ \alpha\beta L'_2 - \beta^2 L_2 + \alpha N'_2 - \beta N_2 \} > 0 \quad \dots \quad (1.27)$$

Now, from (1.6) we have

$$\alpha\beta L'_0 - \beta^2 L_0 = \alpha\beta^2(a^2 - c^2) \left[\begin{matrix} \theta \\ 2, \frac{3}{2} \end{matrix} \right] \quad \dots \quad (1.28)$$

$$\begin{aligned} \alpha\beta L'_2 - \beta^2 L_2 + \alpha N'_2 - \beta N_2 = & \frac{1}{2} \alpha\beta^2 \left\{ -a^2 \left[\begin{matrix} \theta \\ 2, \frac{3}{2} \end{matrix} \right] - c^2 \left[\begin{matrix} 2c^2 - \theta \\ 1, \frac{5}{2} \end{matrix} \right] + c^4 \left[\begin{matrix} 4c^2 - \theta \\ 1, \frac{7}{2} \end{matrix} \right] \right. \\ & \left. - a^2 c^2 \left[\begin{matrix} 2c^2 - \theta \\ 2, \frac{5}{2} \end{matrix} \right] \right\} \quad \dots \quad (1.29) \end{aligned}$$

It is obvious from (1.28) that the first term in (1.27) is always positive except in the case of a sphere when it just vanishes. The second term in (1.27) is always finite. Hence, 'for every given eccentricity it is *always possible* to find out a value of μ such that the condition (1.27), i.e. the condition (1.25) is obeyed.' This proves that for all spheroidal shapes (barring a sphere), stratification in planes parallel to the equatorial plane is possible under self-gravitation and the corresponding model will possess equatorial acceleration.

In the special case $\mu = 1$,

$$\frac{\beta^2}{2C} \cdot \omega^2(\text{pole}) = (\alpha\beta L'_0 - \beta^2 L_0) + (\alpha\beta L'_2 - \beta^2 L_2) + (\alpha N'_2 - \beta N_2) \quad \dots \quad (1.30)$$

This equation can be simplified and put into the form

$$\frac{1}{2} \omega^2(\text{pole}) = \frac{1}{2} C \alpha \left[(a^2 - c^2) \left[\begin{matrix} (2c^2 + \theta)\theta^2 \\ 2, \frac{7}{2} \end{matrix} \right] + 2c^2(a^2 - c^2) \left[\begin{matrix} \theta^2 \\ 2, \frac{7}{2} \end{matrix} \right] - 2c^4 \left[\begin{matrix} \theta \\ 1, \frac{7}{2} \end{matrix} \right] \right] \quad (1.31)$$

Hence, for $a \rightarrow c$,

$$\frac{\omega^2}{2}(\text{pole}) \rightarrow \text{a negative value};$$

but for $c \rightarrow 0$,

$$\frac{\omega^2}{2}(\text{pole}) \rightarrow \frac{1}{2} C \alpha \left[\begin{matrix} 1 \\ 2, \frac{1}{2} \end{matrix} \right] > 0.$$

Hence, the equilibrium is real for eccentricities sufficiently high under self-gravitation only. For cases where $a^2 > 2c^2$ this is always possible.

Sec. 2.

EQUILIBRIUM UNDER THE GENERAL QUADRATIC LAW OF STRATIFICATIONS.

1. In this case, we assume the law of stratifications to be given by (1) with the boundary (2) as before.

Then, all the equations from (1.1) to (1.8) hold good in toto, λ being no longer zero. Besides, the equations of motion are still given by (1.10) but, instead of (1.11) we have

$$\frac{\partial}{\partial z^2} \left(\frac{1}{2} \rho \omega^2 \right) = -\rho_0 \cdot \lambda \alpha \frac{\partial V}{\partial z^2} + \rho_0 \mu \beta \frac{\partial V}{\partial r^2} \dots \dots \dots (2.1)$$

Hence, substituting from (1.1) and integrating partially we have, as before,

$$\frac{1}{2} \rho \omega^2 = \rho_0 C [(\mu \beta L - \lambda \alpha L') z^2 + (\mu \beta M - \lambda \alpha M') r^2 z^2 + \frac{1}{2} (\mu \beta N - \lambda \alpha N') z^4] + F(r^2). \dots (2.2)$$

Using the same arguments as given in Sec. 1b, we assume that the arbitrary function $F(r^2)$ and the pressure p are still of the same form as in equations (1.13) and (1.14), though the constants appearing in the right-hand-side of these equations have in general different values in this case.

Hence (2.2) takes the form

$$\frac{1}{2} \rho \omega^2 = \rho_0 C [K_0 + K_1 r^2 + (\mu \beta L - \lambda \alpha L') z^2 + (\mu \beta M - \lambda \alpha M') r^2 z^2 + K_2 r^4 + \frac{1}{2} (\mu \beta N - \lambda \alpha N') z^4]. \dots (2.3)$$

Now proceeding exactly as in the case of plane stratifications the twelve new equations corresponding to (1.16) become

$$\left. \begin{aligned} \alpha(A_1 - A_0) &= K_0 + L \dots (1) \\ 2\alpha^2(A_4 - A_1) &= K_1 + M - \lambda \alpha L \dots (2) \\ \alpha\beta(A_3 - A_1 - A_2) &= M' - \lambda \alpha L' \dots (3) \\ \alpha\beta(A_3 + A_4) &= \lambda N \dots (4) \\ 3\alpha^2 A_4 &= \lambda \alpha M - K_2 \dots (5) \\ 2\alpha\beta^2(A_3 + A_5) &= \lambda \alpha N' + \mu \beta N \dots (6) \end{aligned} \right\} \left. \begin{aligned} \beta(A_2 - A_0) &= L' \dots (7) \\ \alpha\beta(A_3 - A_1 - A_2) &= M' - \lambda \alpha L' \dots (8) \\ 2\beta^2(A_5 - A_2) &= N' - \mu \beta L' \dots (9) \\ 2\alpha\beta^2(A_3 + A_5) &= \lambda \alpha N' + \mu \beta M' \dots (10) \\ \alpha\beta(A_3 + A_4) &= \lambda M' \dots (11) \\ 3\beta^2 A_5 &= \mu N' \dots (12) \end{aligned} \right\} (2.4)$$

As $M' = N$ these equations are, as before, not all independent; equations (3), (4) and (6) being the same as (8), (11) and (10) respectively. Besides the number of unknown constants is still only 9 and hence as before, the equations are just sufficient to determine the unknown constants. The solutions are given by

$$\left. \begin{aligned} 2\beta^2 A_0 &= \frac{1}{3}(2\mu - 3)N' + (\mu - 2)\beta L' \dots (i) \\ 2\alpha\beta^2 A_1 &= \frac{1}{3}(3\lambda - 4\mu + 3)\alpha N' + (\mu - 2)\beta M' + (2\lambda - \mu)\alpha\beta L' \dots (ii) \\ 2\beta^2 A_2 &= \frac{1}{3}(2\mu - 3)N' + \mu\beta L' \dots (iii) \\ 2\alpha\beta^2 A_3 &= \frac{1}{3}(3\lambda - 2\mu)\alpha N' + \mu\beta N \dots (iv) \\ 2\alpha\beta^2 A_4 &= -\frac{1}{3}(3\lambda - 2\mu)\alpha N' + (2\lambda - \mu)\beta N \dots (v) \\ 3\beta^2 A_5 &= \mu N' \dots (vi) \\ 2\beta^2 K_0 &= -2\beta^2 L + 2\alpha(\lambda - \mu + 1)(\beta L' + N') + (\mu - 2)\beta M' \dots (vii) \\ \beta^2 K_1 &= \alpha\beta\{\lambda(\beta L - 2\alpha L') + \mu\alpha L'\} - \beta^2 M + \alpha^2(2\mu - 2\lambda - 1)N' \\ &\quad + 2\alpha\beta(\lambda + 1 - \mu)N \dots (viii) \\ 2\beta^2 K_2 &= 2\lambda\alpha\beta^2 M - 3\alpha^2\beta(2\lambda - \mu)N + \alpha^2(3\lambda - 2\mu)N' \dots (ix) \end{aligned} \right\} (2.5)$$

2. THE REALITY CONDITIONS.

In order that the above solutions may conform to real conditions the minimum value of $\rho\omega^2$ obtained from (2.3) for $0 < \alpha r^2 < 1$ and $0 < \beta z^2 < 1$ must not be negative. This is both necessary and sufficient. As the form of $\rho\omega^2$ is extremely general having altogether three degrees of freedom, represented by the parameters λ , μ and the eccentricity of the boundary spheroid, a general discussion is not likely to lead to any specific conclusions. We should, however, bear in mind that given any set of values of λ , μ and the eccentricity it is always possible to test whether equilibrium is possible for the set or not. Besides, it will be profitable to remember that we always have a real solution for the case where $\lambda = \mu$ for any eccentricity whatsoever if λ ($= \mu$) lies between 0 and 1. For, thereby, the problem reduces to that of the stratification in spheroids similar to the boundary and in such a case equilibrium always exists, as has been shown by Dive (1930) and also by the author in a previous paper (Ghosh, 1950A).

3. THE SURFACE ANGULAR VELOCITY AND THE CONDITIONS FOR EQUATORIAL ACCELERATION.

Assuming that the reality conditions for ω are obeyed, we propose now to obtain the general expression for the surface angular velocity and deduce therefrom 'the conditions for the existence of equatorial acceleration'.

Substituting the values of K_0 , K_1 , K_2 from (2.5) in (2.3) we have

$$\begin{aligned} \frac{\rho\omega^2\beta^2}{\rho_0'} = & \left\{ -2\beta^2 L + 2\alpha(1-\mu)(\beta L' + N') + (\mu-2)\beta M' + 2\beta^2(\mu\beta L z^2 + \frac{1}{2}\mu\beta N z^4) \right\} \\ & + r^2 \left[2 \left\{ \mu\alpha^2(\beta L' + N') + 2\alpha\beta(1-\mu)N - (1-\mu)\alpha^2 N' - \beta^2 M \right\} + 2\mu\beta^3 M z^2 \right. \\ & \left. + r^2 \left\{ \alpha^2\mu(3\beta N - 2\alpha N') \right\} \right] \\ & + \lambda\alpha \left[\left\{ (2\beta L' + N') - 2\beta^2(L' z^2 + \frac{1}{2}N' z^4) \right\} \right. \\ & \left. + r^2 \left[2 \left\{ \beta(\beta L + 2N) - 2\alpha(\beta L' + N') \right\} - 2\beta^2 M' z^2 + r^2 \left\{ 2\beta^2 M - 6\alpha\beta N + 3\alpha^2 N' \right\} \right] \right]. \quad (2.6) \end{aligned}$$

The first two terms together really form the entire expression for the case corresponding to $\lambda = 0$, discussed in section 1, and can always be put in the form given by the right-hand-side of (1.19a) when αr^2 is replaced by $(1-\beta z^2)$ in accordance with (2). Hence, the first two terms reduce to

$$2(1-\mu\beta z^2) \left[-\beta^2 L - \beta N + \alpha(\beta L' + N') + (1-\beta z^2) \left\{ -\frac{\beta^2}{\alpha} \cdot M - \alpha N' + 2\beta N \right\} \right]$$

on the surface. Similarly substituting $(1-\beta z^2)$ for αr^2 in the third term, it reduces on simplification to

$$2\lambda\alpha r^2 \left[\beta^2 L + \beta N - \alpha\beta L' - \alpha N' + (1-\beta z^2) \left\{ -2\beta N + \alpha N' + \frac{\beta^2}{\alpha} \cdot M \right\} \right].$$

Combining these two results (2.6) gives

$$\begin{aligned} \frac{\rho_s \cdot \omega_s^2 \cdot \beta^2}{\rho_0 \cdot C} = & 2(1-\lambda\alpha r^2 - \mu\beta z^2) \left[-\beta^2 L - \beta N + \alpha(\beta L' + N') + (1-\beta z^2) \right. \\ & \left. \left\{ -\frac{\beta^2}{\alpha} \cdot M - \alpha N' + 2\beta N \right\} \right] \end{aligned}$$

and hence, cancelling ρ_s from both sides ($\lambda, \mu \neq 1$) we have

$$\frac{\omega_s^2}{2} = \frac{C}{\beta^2} \left[-\beta^2 L - \beta N + \alpha(\beta L' + N') + (1 - \beta z^2) \left\{ -\frac{\beta^2}{\alpha} M - \alpha N' + 2\beta N \right\} \right] \quad \dots \quad (2.7)$$

the same expression as in (1.20) with altered meanings for L, M, N , etc.

Differentiating (2.7) we have, as before,

$$\frac{d}{dz^2} \left(\frac{\omega_s^2}{2C} \right) = \frac{1}{\beta} \left\{ \frac{\beta^2}{\alpha} M + \alpha N' - 2\beta N \right\} \cdot \dots \quad (2.8)$$

Arguing as in the case $\lambda = 0$, we see that ω_s^2 must change monotonically in every case for a fixed set of values of λ and μ .

Now, substituting the values of M, N', N from (1.4) we have

$$\frac{d}{dz^2} \left(\frac{\omega_s^2}{2C} \right) = \lambda \left\{ \frac{\beta}{\alpha} M_1 + \frac{\alpha}{\beta} N_1' - 2N_1 \right\} + \mu \left\{ \frac{\beta}{\alpha} M_2 + \frac{\alpha}{\beta} N_2' - 2N_2 \right\} \cdot \dots \quad (2.9)$$

Replacing M_1, M_2 , etc. by the values given in (1.6), (2.9) can be reduced to

$$\begin{aligned} \frac{d}{dz^2} \left(\frac{\omega_s^2}{2C} \right) = \lambda(a^2 - c^2) \left\{ \frac{2a^2}{c^2} \left[\frac{\theta}{4, \frac{3}{2}} \right] - \frac{a^2 - c^2}{a^2 c^2} \left[\frac{\theta^3}{4, \frac{5}{2}} \right] \right\} - \mu(a^2 - c^2) \times \\ \left\{ 2 \frac{c^2}{a^2} \left[\frac{\theta}{2, \frac{7}{2}} \right] + \frac{(a^2 - c^2)}{a^2 c^2} \left[\frac{\theta^3}{3, \frac{7}{2}} \right] \right\} \cdot \dots \quad (2.10) \end{aligned}$$

Since (2.10) vanishes for $a = c$, the first obvious conclusion is that for perfectly spherical boundaries there cannot be any variation in the angular velocity over the surface.

For the general case of any eccentricity we note, first, that the coefficient of $-\mu$ on the right-hand-side of (2.10) is always positive. Again, the case $\lambda = \mu = 1$ has been investigated in a previous paper (Ghosh, 1950A) and was found to be a case of equatorial retardation. From this we conclude that the coefficient of λ , for any given eccentricity must be positive and, further, exceed numerically the value of the coefficient of $-\mu$. This result, which we prove here easily by indirect argument, would involve a laborious calculation for direct verification.

Now, we see that the right-hand-side of (2.10) can be negative only for values of $\lambda < \mu$, both λ and μ being positive. In other words a necessary condition for the existence of equatorial acceleration is

$$0 < \lambda < \mu < 1. \quad \dots \quad (2.11)$$

It is interesting to note that all cases for which $\lambda < 0$ must result in equatorial acceleration but such cases may not yield any natural models. For even if equilibrium be possible there cannot be stability as the density would increase outwards along an equatorial radius.

We also observe that for any given eccentricity the upper limit to the value of λ corresponding to an assigned μ consistent with equatorial acceleration can always be obtained from (2.10).

Thus, we conclude that 'equatorial acceleration under the law of stratification (1) is possible only for those models for which the stratifications (in similar spheroids) are much flatter than the boundary spheroid, i.e. the ratio of the major axis to the minor axis is higher for the equidensity surfaces than for the boundary spheroid; stratifications in planes parallel to the equatorial plane is also possible for such cases.'

Finally, it is interesting to make the following observation regarding equation (2.8).

The equation is of the form

$$\frac{d}{dz^2} \omega_s^2 = \text{const.}$$

When the surface is nearly spherical this is equivalent to

$$\frac{\partial}{\partial \phi} \omega_s^2 = \text{const.} \times \sin 2\phi$$

where ϕ is the latitude.

A form like this was actually proposed by Faye to explain the observed variation of the surface-angular velocity of the sun.

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IS THERE A 'WILD TYPE' IN THE GENUS *FUSARIUM*

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The taxonomy and nomenclature of the genus *Fusarium* has been the subject of controversy for a long time past and different systems of classification have been proposed (Wollenweber and Reinking, 1935; Snyder and Hansen, 1940, 1941, 1945). While the systems proposed from time to time have been extremely divergent and controversial, there has been some measure of agreement among *Fusarium* taxonomists on the use of the 'criteria of the norm' (Wollenweber *et al.*, 1925) in the various taxonomic groupings proposed. Recently, however, the validity of the use of these criteria in *Fusarium* nomenclature has been questioned by Miller (1945, 1946a, 1946b). According to Miller the results of prolonged cultural studies of various isolates of this genus in the traditional manner and aimed at specific identification would be unreliable since mutation is a very common occurrence in the genus, particularly when it is grown on artificial media. It has been stated that the 'wild type' of muskmelon wilt *Fusarium*, as Miller calls it, should be the basis for a sound taxonomy of the genus. The 'wild type' as conceived by Miller is the type that usually occurs in nature as a form (or forms) that, when cultured on most artificial media, produces abundant aerial mycelium on which conidia, mostly non-septate, are borne rather sparsely.' (Miller, 1945, p. 41). However, continued culturing, according to Miller, results in the loss of the 'wild type', being crowded out by mutants which are characterised by prolific sporulation (0.3- or more septate conidia) and an adpressed type of growth with little or no aerial mycelium. Following up this hypothesis, Miller (1946a, 1946b) has further suggested that the traditional 'sporodochium' in the genus *Fusarium* is synonymous with 'patch mutants' encountered during his studies and, hence, has suggested that these should not be the basis for a sound classification of the genus. These suggestions indicated the importance of studying the 'wild type' among *Fusaria* generally and finding out if the concept put forward by Miller was true of all *Fusaria*. A study was, therefore, undertaken where *Fusaria* were cultured immediately after isolation from a number of hosts as well as from soil with a view to include predominantly saprophytic forms also. Altogether 87 isolates from six different hosts and 20 isolates from soil are included in the present investigation.

EXPERIMENTAL.

I. Isolations from wilted or diseased plants.

Isolations were made from the following hosts :

Host.	Nature of disease.	Locality.
1. Horsegram .. (<i>Dolichos biflorus</i> Linn.) ..	Damped-off seedlings.	Coimbatore.
2. Green gram .. (<i>Phaseolus radiatus</i> Linn.) ..	Wilted plants.	Do.
3. Red gram .. (<i>Cajanus cajan</i> (Linn.) Millsp.) ..	Do.	Do.

Host.	Nature of disease.	Locality.
4. Brinjal (<i>Solanum melongena</i> L.)	Wilted plants.	Coimbatore.
5. Cluster bean (<i>Cyamopsis tetragonoloba</i> Taub.)	Do.	Coimbatore and Kovilpatti.
6. Pineapple (<i>Ananas sativus</i> Schult.)	Do.	Kovilpatti.

The material in each case was surface sterilised in 1/1000 aqueous mercuric chloride for 40-50 seconds and washed in several changes of sterile water and plated out on potato dextrose agar (dextrose 2 per cent) in Petri dishes. Transfers were made from growth in Petri dishes to potato dextrose agar slants and on the 3rd to 5th day growth in Petri dishes as well as slants was examined for characters such as type of growth, aerial mycelium, sporulation, etc. The cultural characters in Petri dishes and slants were similar. The results are tabulated (Tables I and II). Photographs of the slant cultures of some of the isolates taken soon after isolation are presented in Plate XVIII.

TABLE I.

Summarising details regarding number of isolates of *Fusaria* falling under different cultural types.

Sections and Source.	No. of isolates studied.	Aerial mycelium abundant and cottony.		Aerial mycelium forming a thin mat.		Aerial mycelium absent.	
		S. & P. none.	S. & P. present.	S. & P. none.	S. & P. present.	S. & P. none.	S. & P. present.
MARTIELLA—							
Horsegram ..	2	..	2	..	..	..	..
Green gram ..	3	1	1	..	..	..	1
Brinjal ..	12	8	1	..	..	..	3
Cluster bean ..	3	..	..	..	..	..	3
Pineapple ..	9	6	..	..	..	1	2
Soil ..	12	4	5	..	..	..	3
ELEGANS—							
Brinjal ..	1	1	..	..	..	..	..
Cluster bean ..	15	2	..	2	2	4	5
Soil ..	5	4	..	..	..	1	..
GIBBOSUM—							
Brinjal ..	1	..	1	..	..	..	..
Cluster bean ..	1	..	..	..	1	..	..
Soil ..	2	2	..	..	..	..	..
ARTHROSPORIELLA—							
Cluster bean ..	2	1	1	..	..	..	..
LATERITIUM(?)—							
Red gram ..	9	1	5	..	1	..	2
UNIDENTIFIED—							
Green gram ..	10	8	..	..	..	..	2
Red gram ..	8	4	4	..	..	..	..
Brinjal ..	8	7	1	..	..	..	..
Cluster bean ..	3	..	..	..	..	3	..
Soil ..	1	1	..	..	..	..	..
TOTAL ..	107	50	21	2	4	9	21

S. = Sporodochia.

P. = Pionnotes.

TABLE II

Summarising details regarding number of isolates of *Fusaria* producing microconidia, macroconidia and chlamydospores.

Section and Source.	No. of isolates studied.	Microconidia.			Macroconidia.			Chlamydospores.	
		None.	Sparse.	Abundant.	None.	Sparse.	Abundant.	None.	Present.
<i>ARTIELLA</i> —									
Horsegram ..	2	..	1	1	..	..	2	..	2
Green gram ..	3	..	..	3	..	1	2	..	3
Brinjal ..	12	..	7	5	..	4	8	..	12
Cluster bean ..	3	..	3	..	..	..	3	..	3
Pineapple ..	9	..	6	3	..	3	6	..	9
Soil ..	12	..	1	11	..	1	11	..	12
<i>ELEGANS</i> —									
Brinjal ..	1	..	..	1	..	1	..	..	1
Cluster bean ..	15	..	3	12	..	11	4	..	15
Soil ..	5	..	..	5	..	3	2	..	5
<i>GIBBOSUM</i> —									
Brinjal ..	1	1	..	..	..	..	1	..	1
Cluster bean ..	1	..	1	..	..	..	1	..	1
Soil ..	2	2	..	..	..	2	..	..	2
<i>ARTHROSPORIELLA</i> —									
Cluster bean ..	2	..	2	..	..	..	2	1	1
<i>LATERITIUM</i> (?)—									
Red gram ..	9	..	1	8	..	9	..	6	3
<i>UNIDENTIFIED</i> —									
Green gram ..	10	1	6	3	6	2	2	4	6
Red gram ..	8	1	2	5	7	..	1	1	7
Brinjal ..	8	4	..	4	5	1	2	..	8
Cluster bean ..	3	..	3	..	3	..	..	..	3
Soil ..	1	1	..	..	1	..	..	..	1
TOTAL ..	107	10	36	61	22	38	47	12	95

CONCLUSIONS.

Nature of growth.—The type of growth varied widely in the case of the different isolates. There were various gradations from types having abundant aerial mycelium to those having none and exhibiting a typically adpressed growth. Where aerial mycelium was present the growth could be woolly, loosely or compactly fluffy, or cottony. Of the 87 isolates, 27 showed typical adpressed growth with no aerial mycelium and the rest had some or abundant aerial mycelium. The amount of aerial mycelium in the different isolates has not been easily assessable, due to its great variability and the different forms in which it occurred. The noteworthy fact was that considerable variability was seen among the 'wild types' studied and it would appear that the 'wild type' concept should embrace all forms with no aerial mycelium and those with aerial mycelium and also all the intergrading types.

Sporulation.—In the matter of sporulation, again, a wide divergence in behaviour has been observed in the isolates studied. These may be summarised as follows:

Out of the 87 isolates, only 8 did not produce any conidia: others produced either microconidia, macroconidia or both.

Microconidia.—Only 9 isolates did not produce any microconidia. Microconidia when produced were generally scattered in the aerial mycelium, if present, or borne

on false-heads. In some of the isolates these were few, but in the majority of isolates these were produced abundantly. They were usually non-septate although in a few cases they were also septate.

Macroconidia.—The majority of isolates produced macroconidia. 21 of the 87 isolates did not produce macroconidia. Of these, as stated above, 8 did not produce microconidia either. The various isolates differed in the abundance of macroconidia produced and their septation. Data regarding abundance of various types of spores in some of the isolates are presented in Table III.

TABLE III.

Showing percentage occurrence of conidia of varied septation in some of the isolates.

Culture No.	Section.	Percentage occurrence.					
		0-sept.	1-sept.	2-sept.	3-sept.	4-sept.	5-sept.
2	Martiella	..	4	5	89	2	..
10	"	7	9	10	73	1	..
32	"	2	7	..	60	24	7
33	"	16	12	2	65	5	..
40	"	7	5	4	73	11	..
45	"	10	9	7	56	17	1
47	"	3	7	..	62	25	3
50	"	1	1	..	82	14	2
52	" (?)	9	22	3	61	5	..
56	Martiella	5	13	3	73	6	..
74	Arthrosporiella	1	2	1	69	17	10
75	Elegans	22	1	..	12	38	27
78	Gibbosum	..	..	..	9	12	76
89	Elegans	62	4	..	13	19	2
103	Martiella	..	..	..	94	6	..
105	"	..	..	..	85	15	..
107	Martiella (?)	17	19	13	51	..	..
108	Martiella	19	45	19	17	..	..
119	"	..	..	..	65	35	..

These data show that a number of isolates produced an abundance of 3-septate macroconidia. Higher septation occurred in some isolates, although these were not as abundantly produced as 3-septate conidia in certain cases. Analysis of data regarding septation of spores indicates the following:—

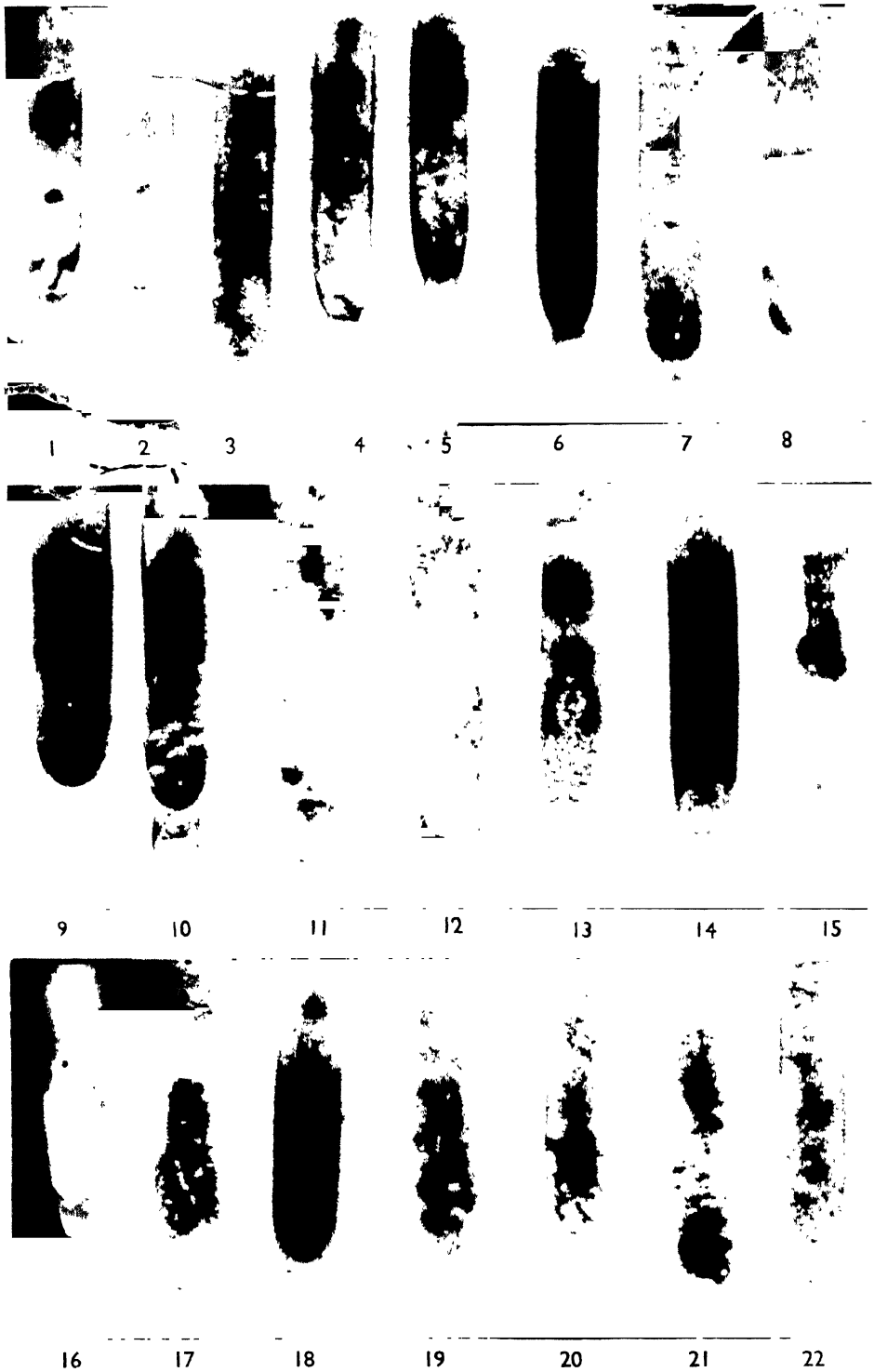
Number of isolates producing macroconidia of minimum septation 3	66
Number of isolates with macroconidia of maximum septation 3	30
" " " " " 4	16
" " " " " 5	18
" " " " " 6 and above	2

It will be evident from these that the majority of the isolates commonly produced macroconidia of minimum septation three, although increased septation over three was not uncommon.

Sporodochia and Pionnotes.—Of the 87 isolates sporodochia or pionnotes were observed in 35. Typical sporodochia developed in 25.

Chlamydospores.—71 of the 87 isolates produced chlamydospores immediately after isolation.

Taxonomy of the isolates.—Most of the isolates have been provisionally placed in sections following Wollenweber and Reinking's (1935) classification, and this is indicated in Tables I and II. It is interesting to note that four different sections



are represented in the present collection of isolates. The section *Elegans*, considered to be the most important from the plant disease point of view, is represented at least by 16 isolates; the section *Martiella* by 31; the section *Gibbiform* by 2; the section *Arthrosporiella* by 2 and the section *Lateritium* (?) by 9. The range of variation in the 'wild type' within these taxonomic groupings may now be analysed.

Elegans.—15 of the isolates belonging to this section were isolated from wilted cluster bean and one from brinjal. The 'wild type' in this group was variable and was represented by the following five forms:—

(i) Growth loosely fluffy, with aerial mycelium, moderately or abundantly developed. Mycelium may be white or coloured, with or without stroma. Microconidia present, moderately abundant, in false heads or scattered in aerial mycelium. Macroconidia, not abundant, 3-5-septate, scattered and not forming sporodochia or pionnotes. The single isolate from brinjal and a few isolates from cluster bean fell into this group.

(ii) Growth typically adpressed with little or no aerial mycelium, except at top of slant. Microconidia abundant to prolific, in false heads or scattered. Macroconidia present, 3-5-septate, scattered. Pionnotes or sporodochia none.

(iii) Growth typically adpressed with little or no aerial mycelium. Microconidia present, few or abundant, mostly in false heads or scattered. Macroconidia present, 3-5-septate, in sporodochia or pionnotes.

(iv) Growth of fungus forming a thin mat, often compact and pale white, on agar surface. Microconidia were produced prolifically, mostly in false heads or else scattered. Macroconidia ranged up to 5-septate and were borne scattered. Typical sporodochia or pionnotes none.

(v) Growth of fungus forming a thin mat, often compact and pale white, on agar surface. Microconidia produced prolifically, mostly in false heads, also scattered. Macroconidia 3-5-septate, in sporodochia and pionnotes.

Martiella.—Isolates belonging to this section were isolated from a number of different hosts and the assignment of these on basis of host is: Horsegram 2, Green gram 3, Brinjal 12, Cluster bean 3 and Pineapple 9. As in the *Elegans* group of isolates, here also variation was noticed in the 'wild type' and an analysis of the data is suggestive of a concept of 'wild type' embracing the following forms:—

(i) Growth fluffy, with aerial mycelium moderately or abundantly developed, loose or compact. Stroma of a pale bluish green colour may or may not be present. Microconidia present, abundant. Macroconidia up to 3-septate, numerous, produced in pionnotes. Sporodochia none. Represented by a single isolate from horsegram.

(ii) Growth fluffy, with aerial mycelium moderate to abundant, loose or compact. Stroma of a pale blue to bluish green colour may be present. Microconidia abundant. Macroconidia 3-5-septate, typically produced in sporodochia. Represented by isolates from horsegram, green gram and brinjal.

(iii) Growth fluffy, sometimes only in patches. Microconidia few to abundant. Macroconidia 3-5-septate, not abundant and borne scattered. Sporodochia or pionnotes none. Represented by isolates from green gram, brinjal and pineapple.

(iv) Growth typically adpressed with no aerial mycelium, except sometimes at top of slant. Micro- and macroconidia abundant and produced prolifically in sporodochia and pionnotes—the typically 'pionnotal' type of culture. Macroconidia sometimes up to 6-septate. Represented by isolates from green gram, brinjal, cluster bean and pineapple.

(v) Growth typically adpressed with no aerial mycelium. Micro- and macroconidia few or only moderately abundant, scattered. Macroconidia up to 3-5-septate. Sporodochia and pionnotes none. Represented by isolates from brinjal and pineapple.

It is interesting to note that in the case of each host (except cluster bean) the 'wild type' is represented by more than one form. Even in the case of cluster bean greater variety in 'wild type' would have been recorded if a larger number of isolates had been obtained under this section of the genus from this host.

Sections other than Elegans and Martiella.—Consideration of the 'wild type' with reference to isolates falling under the sections Gibbosum and Arthrosporiella will not be taken up in the present paper since these are poorly represented in the present series of isolates. Also, the nine isolates from red gram will not be considered since these have been only provisionally placed in the section Lateritium. However, it may be mentioned here that the identification of these, provisionally or otherwise, has been possible only because they sporulated freely immediately after isolation. Most of these produced an abundance of macroconidia, up to 3-septate and more, either scattered or in sporodochia or pionnotes; also there were types with well-developed aerial mycelium and the truly pionnotal forms with intermediate forms between them.

II. Isolations from soil.

Isolations of *Fusaria* were made from Udamalpet wilt-sick cotton soil using the root-burial technique (Subramanian, 1946). Observations similar to those made in the case of the isolates from wilted plants were made in this case also and are tabulated (Tables I and II).

CONCLUSIONS.

Nature of growth.—In general, the wide variability noticed in the case of the isolates from diseased plants was generally true of the soil isolates also. Of the twenty isolates studied 16 had moderate to abundant aerial mycelium and the remaining four showed typically adpressed growth.

Sporulation.—Of the 20 isolates, only one did not produce any conidia; all the others produced either microconidia or macroconidia or both in varying abundance. Microconidia when present were produced in abundance mostly in false heads and only rarely scattered. The majority (19) of the isolates produced macroconidia. Macroconidia were few to many and often produced in sporodochia or pionnotes. Typical sporodochia and often pionnotes were produced in 8 of the 20 isolates. Analysing the data regarding septation of spores, the position is as follows:

No. of isolates producing macroconidia of minimum septation	3	..	19
No. of isolates producing macroconidia of maximum septation	3	..	11
" " " " "	4	..	6
" " " " "	5	..	2

Thus, as in the case of the isolates from the diseased plants, the majority of the isolates produced conidia with a maximum septation of three, although higher septation was not uncommon.

Chlamydospores were observed originally (4 days after transfer to slants when observations tabulated above were made) only in 13 of the 20 isolates. However, they were observed in the remaining isolates after 10 days incubation when re-examined.

Taxonomy of the isolates.—The isolates have been placed in three different sections, following Wollenweber and Reinking (1935). A single isolate which produced only chlamydospores has been left unidentified. 12 of the isolates fell into section Martiella, 5 into Elegans and 2 into Gibbosum.

As in the case of the isolates obtained from wilted plants, the soil isolates of Martiella *Fusaria* exhibited wide range in 'wild type', as follows:

- (i) Growth fluffy with aerial mycelium moderate to abundant. Microconidia abundant mostly in false heads, also scattered. Sporodochia or pionnotes none. Represented by 4 isolates.

(ii) Growth fluffy with aerial mycelium moderate to abundant. Microconidia present; abundant, in false heads or scattered. Macroconidia abundant, up to 3-septate, typically produced in sporodochia of a cream or blue or bluish gray colour. Represented by 5 isolates.

(iii) Growth typically adpressed with prolific development of sporodochia and pionnotes, the surface of culture showing an oily appearance. Represented by 3 isolates.

The number of soil isolates obtained in the sections *Elegans* and *Gibbosum* were few and definite conclusions on the 'wild type' in these may have to await further work. Nevertheless, it is interesting to note that the five soil isolates in section *Elegans* fall into two categories: (i) growth fluffy, sometimes tending to be cottony, with abundant microconidia, mostly in false heads, and fewer macroconidia, scattered; (ii) growth typically adpressed with abundant development of sporodochia and pionnotes.

DISCUSSION.

The present investigation, which was taken up to elucidate the question of 'wild type' in *Fusaria*, has yielded some interesting data bearing on the problem. The data presented here are the result of study of a number of isolates of *Fusaria* obtained from wilted or infected crop plants and also from soil, these isolations having been intended to include both parasitic and saprophytic forms. Also, the isolates made were subjected to study immediately after their isolation and it is believed that these would, therefore, be the nearest possible approximation to the state in which *Fusaria* occur in nature. The results just presented offer strong evidence against Miller's (1945, 1946a, 1946b) recent thesis that the 'wild type' among his muskmelon isolates of *Fusaria* and *Fusaria* generally is 'a form (or forms) that, when cultured on most artificial media, produces abundant aerial mycelium on which conidia, mostly non-septate, are borne rather sparsely'. The evidence at hand falls in line with the recent observations of Snyder *et al.* (1949) on *Fusaria* associated with mimosa wilt, sumac wilt and pine pitch canker. Snyder *et al.* have applied the term 'natural clone' to the 'wild type' among *Fusaria* and have shown that there is a multiplicity of morphologic clones of certain *Fusaria* in nature. The data presented in this paper confirm these observations. A large number of the isolates agreed with Miller's 'wild type' in the development of abundant aerial mycelium; however, they all produced microconidia in abundance and macroconidia were moderately abundant and sometimes prolific, being scattered or clustered in sporodochia. Thus, the epithet 'sparsely sporulating' seems to be inapplicable at least to a large number of isolates obtained fresh and directly from nature. It is true that difficulty has been experienced by a number of workers in the past with regard to sporulation of *Fusaria* and this fact has always been mentioned by workers engaged in the identification of *Fusaria*. Indeed, similar isolates have been obtained in the course of the present investigation and obviously identification of these isolates is a difficult matter. However, such isolates have been few. Doubtless, such forms with abundant aerial mycelium and poor or no sporulation and agreeing with Miller's 'wild type' do occur in nature. But they do not appear to be the only form or state in which *Fusaria* occur in nature. Between the typically 'mycelial' form with poor sporulation and the typically 'sporodochial' or 'pionnotal' form with little or no aerial mycelium, there have been encountered, during the present study, a large number of intergrading forms. Amongst these intergrading forms the wide range of variation noticed has been in respect of one or more characters, like amount of aerial mycelium, sporulation, occurrence of sporodochia or pionnotes, etc., and a large number of such cultural forms were obtained from both wilted and infected crop plants and also from soils. The variation observed, for instance, among isolates classified under *Martiella*, has been so great as to defy exact

description. Such characters like amount of aerial mycelium and abundance of sporulation have been difficult to assess. However, it has been possible to recognise certain broad categories among the isolates belonging to each section, particularly those placed in sections *Martiella* and *Elegans* which are sufficiently represented in the present study. It is, therefore, suggested that *Fusaria* as they occur in nature in a wild state would fall into one or more of these categories enumerated in the text of this paper. Possibly, the case of muskmelon *Fusaria* studied by Miller (1945, 1946a, 1946b) is an instance where all the isolates obtained fell into one and the same category, i.e., the 'mycelial' type with sparse sporulation. However, it would appear that this is not generally true of *Fusaria*. Indeed, there is no positive evidence in this study indicating that the host of choice or saprophytic or parasitic character of the fungi have much to do with the form in which they occur in the wild state. Thus, for instance, *Martiella* *Fusaria* obtained from horsegram fell into two categories, those from green gram into three, those from brinjal and pineapple into four. Similarly, among the *Elegans* *Fusaria* fifteen of the sixteen isolates studied were obtained from cluster bean and these fell into four categories. Thus, the evidence presented does not lend support to the view that *Fusaria* occur only in one form in their wild state, viz., the sparsely sporulating mycelial form. On the other hand, it appears that *Fusaria* occur in nature in a widely varying multiplicity of forms, 'wild types' or 'natural clones', whatever be the term used.

In the context of the present studies mention must also be made of the observations made by Miller (1945, 1946a, 1946b) regarding non-occurrence of sporodochia in the 'wild type' of *Fusaria*. This again, is not generally true of *Fusaria* as borne out by the present study where a large number of isolates were observed to produce sporodochia often within a week after isolation. Apart from this, there have been numerous observations by past workers on the occurrence of sporodochia and spore masses with septate conidia appearing on stems and roots of infected plants, i.e., as they occur in nature. Indeed, suggestions made by *Fusarium* taxonomists regarding the use of natural stems of plants, etc. in cultural studies of the genus is a logical corollary of this fact and is intended to encourage growth of fungus simulating what is obtained in nature. It would, therefore, appear that sporodochia are a characteristic of *Fusaria* as they occur in nature and, hence, should be taken into consideration in taxonomical studies of the genus.

Finally, it may be stated that observations made in the present study have been based on isolates falling mainly under two sections: *Martiella* and *Elegans*. It is reasonable to assume, on the basis of the data herein presented, that there is no fixity in regard to the cultural form in which *Fusaria* occur in nature as is shown by the varied type of growth obtained in first isolations. Hence, the question of the need for a concept of 'wild type' in the genus may have to be re-examined. Further work on these lines on a larger number of isolates belonging to different sections from different hosts and different geographic entities is expected to throw more light on the subject. The main purport of this paper is to stress two important facts which have emerged as a result of this study, and should be taken into account in future taxonomic studies on the genus: firstly, the fact that *Fusaria* occur in nature in a wild state in a multiplicity of forms and exhibiting wide range of variation in respect of one or more characters; secondly, the fact that sporodochia are a characteristic of *Fusaria* in artificial cultures when studied immediately after isolation and, hence, appear to be a natural characteristic of the genus as it occurs in nature.

SUMMARY.

The results are presented of a study undertaken in order to elucidate the question of 'wild type' in the genus *Fusarium*.

A number of *Fusaria* were studied in culture immediately after their isolation from diseased or wilted plants and from soil. Amongst the isolates studied at least four taxonomic groups—*Martiella*, *Elegans*, *Gibbosum* and *Arthrosporiella*—were represented.

The *Martiella* and *Elegans* *Fusaria*, in particular, exhibited a very wide range of variation in regard to a number of characters like presence or absence and amount and nature of aerial mycelium, sporulation including production and abundance of microconidia and macroconidia, separation of macroconidia and the abundance of the different septations. Between the typical sparsely sporulating mycelial form and the sporodochial or pionnotal forms with little or no aerial mycelium, there were a large number of intergrading forms. These forms have been broadly classified and are described in the text. Neither the host of choice and parasitic or saprophytic character of the fungi nor the section to which the isolates belonged had anything to do with their cultural characters exhibited in first isolations.

In first cultures, the majority of the isolates sporulated freely producing microconidia. Many of them also produced 3- or more-septate macroconidia.

It is suggested that species of *Fusarium* occur in nature in a multiplicity of forms and not as a single 'wild type' as claimed by Miller. Since sporodochia were produced by a large number of isolates immediately after isolation in first cultures, these are a natural characteristic of the genus and should be of value in taxonomic studies.

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EXPLANATION OF PLATE XVIII.

Photographs of slant cultures of certain *Fusaria* immediately after isolation. Photographs taken one week after transfer to slants.

FIGS. 1-5. *Elegans* isolates from cluster bean.

FIG. 6. *Arthrosporiella* isolate from cluster bean.

FIG. 7. *Gibbosum* isolate from brinjal.

FIG. 8. Unidentified isolate from green gram.

FIGS. 9-16. *Martiella* *Fusaria*. FIGS. 9 and 10 from pineapple, FIGS. 11-16 from brinjal.

FIGS. 17-22. *Lateritium* (?) isolates from red gram.

STRUCTURE AND DEVELOPMENT OF THE SCALES OF FIVE SPECIES OF GREY MULLET OF BENGAL.

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INTRODUCTION.

A comprehensive account of Indian *Mugilidae* is contained in Day's Fishes of India (1878) and in the Fauna of British India—Fishes, Part II (1889). After that the first attempt at their revision was made by Whitehouse (1922). Working on the mullets of Tuticorin, he remarked that 'they form a group whose species it is most difficult to determine'. He also found, like Jacot (1920) that the use of relative body measurements in *Mugils* is difficult as the slight difference in ratios is repeatedly exceeded by individual variations. The need for an accurate knowledge of the specific identity of fishes in fishery development programmes is very well known and this is more so in groups like Mulletts, which are commercially used for culture.

The importance of scales in the classification of fishes has been pointed out by workers like Agassiz (1833), Goodrich (1907), Cockerell (1913) and Lagler (1947). Commenting on the results of Jacot's (*op. cit.*) investigations on the scales of *Mugil cephalus* and *M. curema*, Hubbs (1921) observed that the character of the ctenii of these species are of considerable taxonomic importance. A detailed study of the 5 local species of Mulletts was therefore made to ascertain the degree of variation in their scale characters. As revealed from this study, the size, shape, structure and development of the scales of these species show marked specific variations and these characters provide a reliable key for their correct identification.

GENERAL CHARACTERISTICS OF ADULT SCALES.

The scales of the mullets dealt with in this paper, are either cycloid or ctenoid. They are relatively large in size, and this character together with the presence of lateral line grooves, makes the mullet an unusually favourable subject for lepidological studies (Jacot, *op. cit.*). As in other fishes, regular scales are found on the dorso-lateral surface, while towards the head and the caudal peduncle they become distorted in shape and irregular in pattern. The largest scales are found in the region below the tip of the pectoral fin and they show very little variation in shape and structure.

A typical scale of an adult mullet can be divided into four sectors on its sculptured side, viz., apical, basal and two lateral sectors, using Masterman's (1913) method. Each sector is nearly triangular in shape and the apices are directed towards the nucleus. The nucleus, which term is used here to denote the structural centre of the scale, is generally situated nearer to the apex than to the base. The nucleus is formed by entire or interrupted circuli. Each succeeding circulus from the blank centre outwards is larger than the one preceding it. They may be termed the initial circuli. On the completion of the nucleus they give place to true circuli, which extend across the lateral and basal sectors. The circuli in the basal sector are larger in number than in the lateral sectors, and consequently the inter-circular spaces are narrower in the basal sector. The lateral circuli are coarser than the basal ones. As the scale grows, the surface sculpture in the initial field undergoes a process of disintegration. This begins with the veining on the anterior region of the apical circuli, spreading along the lateral sectors into the basal one. There are well-developed basal radii and they generally converge towards the nucleus. Cycloid scales have well-developed apical radii but the ctenoid scales have no radii in the apical region. In species possessing ctenoid scales, all the scales except the fine ones covering the snout and fin bases, are ctenoid. The ctenii are arranged on the apical region. In species with the ctenii having distinct basal elements, the ctenii get split up, as the fish grows, into apical sharp ctenii and 'basal components' (Ganguly and Mookerjee, 1947). On the contrary Jacot (1920) considered these to be the bases of old worn out ctenii. However, it is preferable to adopt the term he used to designate these structures, viz., ctenobasii as this term is more expressive. As the scale grows, definite rings appear on the scales in the form of breaks in the continuity of the circuli (Kesteven, 1941). These rings are formed by the termination of the circuli in exactly the same way as they terminate at the basal edge of the scale (Jacot, *op. cit.*) and are generally of the same shape as that of the scale itself.

Scale characters for the identification of the Mulletts of Bengal.

1. Scales cycloid	..	..	..	<i>Mugil speigleri</i> (Bleeker).
Scales not cycloid	..	..	..	2
2. Initial circuli entire	..	..	..	3
Initial circuli interrupted	..	..	..	<i>Mugil cephalus</i> Linnaeus.
3. Length of scale 1.5 times or more its breadth	..	..	..	<i>Mugil corsula</i> Ham.
Length of scale less than 1.5 times its breadth	..	..	..	4
4. Length of scale at least 1.1 times more than its breadth	..	..	..	<i>Mugil tade</i> Forsk.
Length of scale equal to its breadth	..	..	..	<i>Mugil parsia</i> Ham.

STRUCTURE AND DEVELOPMENT OF SCALES.

Mugil speigleri (Bleeker).

The scales of *M. speigleri* (Plate XIX, fig. 1) are fairly large and there are 31-33 such scales along the mid-lateral line. An adult scale is cycloid in character and is either equal in length and breadth or slightly broader than long. The basal margin is strongly scalloped. The laterobasal angles are nearly right angles. The basal sector is the largest and here the circuli are very densely arranged. The initial circuli are in the form of concentric rings. The ends of the lateral circuli are slightly deflected outwards. There are generally 5-8 radii arranged fan-wise on the basal sector, and they converge towards the nucleus. The widths of the inter-radial spaces (the distance between the radii on the basal margin of the scale) are not uniform, and generally the two middle ones are wider. They are contained 4-6

times in length of the basal margin. The nucleus is nearly rectangular in shape and is situated nearer the apex than the base, its distance from the base being nearly 1.4 times the distance from the apex. The sculpture on the apical sector is quite characteristic (Text-fig. 1a). In the area nearer the nucleus can be seen irregular patterns formed by the disintegration of the apical portions of the initial circuli. Posterior to this is a region where several apical radii are seen closely arranged. Along the apical margin is a narrow zone which is very thin and delicate and often gets injured while removing the scale from the scale pocket. The apical radii extend to the apical margin, which is also strongly scalloped.

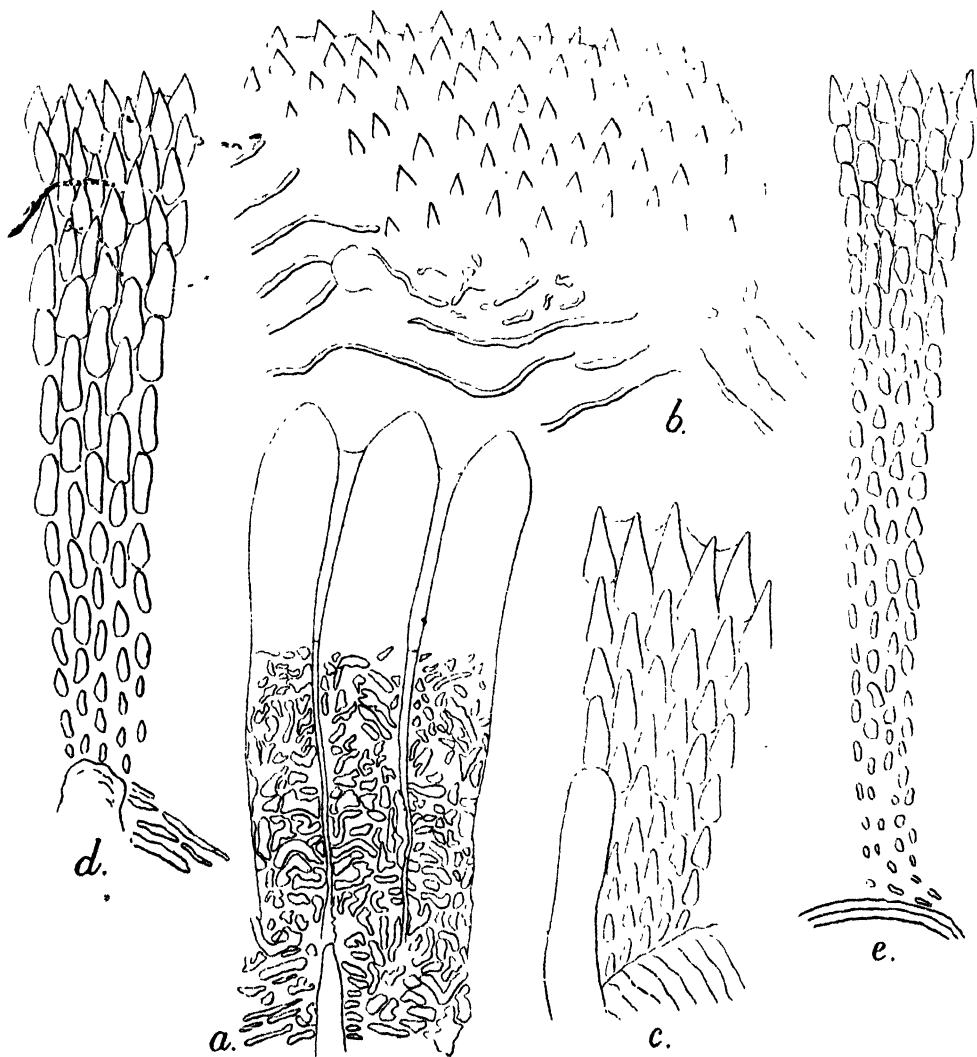


Fig. 1. a. Portion of the apical sector of *M. speigleri* (13.5 cm. long specimen). $\times 54$.
 b. Portion of the apical sector of *M. cephalus* (17.2 cm. long specimen). $\times 54$.
 c. Portion of the apical sector of *M. corsula* (19.2 cm. long specimen). $\times 54$.
 d. Portion of the apical sector of *M. tade* (13.5 cm. long specimen). $\times 54$.
 e. Portion of the apical sector of *M. parsia* (15.0 cm. long specimen). $\times 54$.

The earliest form of scales of this species examined, was from specimens 20 mm. in total length (Text-fig. 2a). The scales at this stage are distinctly broader than long, the length being contained more than 1.2 times in breadth. The nucleus is nearly rectangular in shape, and the initial circuli are seen as continuous rings. The basal radii have been formed and the basal margin is scalloped. The true circuli are densely arranged in the basal region, and generally continued into the lateral regions. The circuli in the apical region are coarser.

The scales of 30 mm. specimens do not show any great structural differences. The lateral line groove has been formed. The scales are less broader than long, the proportion of the length to breadth being 1 : 1.1.

The next stage of development is seen in scales of 48 mm. specimens (Text-fig. 2b). They are now only slightly broader than long; and this proportion remains so in the adult or the length and breadth become equal. The nucleus is situated in the middle of the scale. The sectors are now more clearly distinguishable and the circuli are very densely arranged in the apical sector, where they appear thicker. The majority of the lateral circuli now extend to the margins. The lateral circuli are abruptly bent and continued into the apical region. The lateral line groove is more prominent.

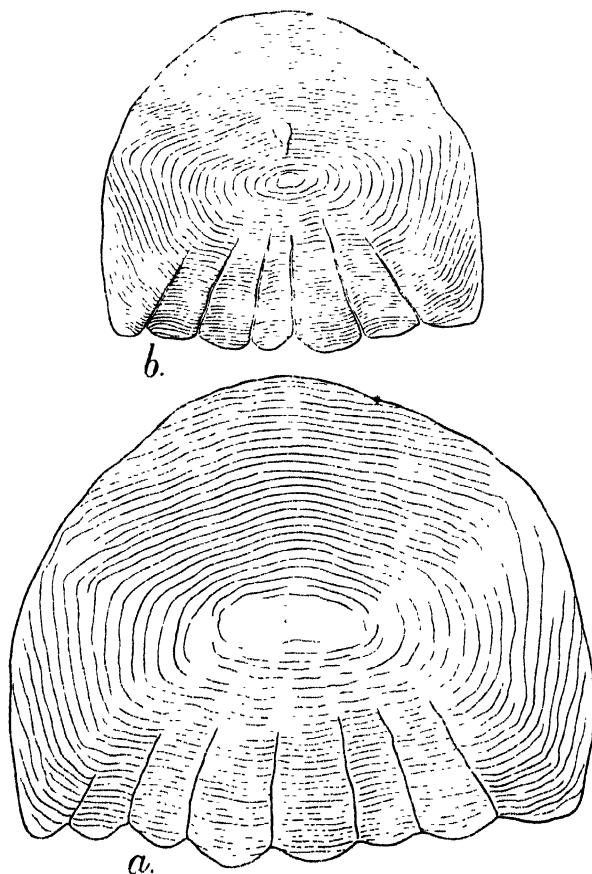


Fig. 2, a. The scale of a 20 mm. long specimen of *M. speigleri*. $\times 51$.
b. The scale of a 48 mm. long specimen of *M. speigleri*. $\times 26$.

In the scale of 60 mm. specimens there is no appreciable progress in development, except that a wide blank margin has been developed at the apex.

In the scales of 76.5 mm. fish the apical radii have begun to appear and the apical margin has become scalloped. The nucleus has come to occupy its position in the adult scales.

As the scale grows, lateral circuli are added on rapidly and the apical portions of the initial circuli begin to disintegrate. In the scales of 140 mm. fish the majority of them can be seen to have broken up and formed the characteristic venation. But a few of the initial circuli remain in tact, and can be seen even in the scales of 233 mm. fish.

Mugil cephalus Linnaeus.

Roxas (1934) figured the scales of adult *M. cephalus* and Jacot (1920) described in detail the development of its sculpture. The scales are relatively small in size. (Plate XIX, Fig. 2) and there are 38-40 of them on the mid-lateral line of the body. They are ctenoid and broader than long (Text fig. 1b), the proportion being about 1 : 1.1. The basal sector is the largest, and the basal margin has a distinct deep notch at its middle. The baso-lateral angles are obtuse and the apico-lateral ones rounded. There are 5-9 primary basal radii, and a varying number of secondary ones. The secondary radii originate from the nuclear region, the basal margin or sometimes from the middle of the basal sector. The radii do not converge towards the nucleus, and are often nearly parallel. They are crowded in the middle of the basal sector. The interradial space is consequently very narrow, and is contained 10-11 times in the length of the basal margin. The nucleus is situated nearer the apex than the base, and its distance from the base is 1.5 times more than its distance from the apex. The nucleus is enclosed by initial circuli interrupted in the lateral sectors. The true circuli extend across the lateral and apical sectors. The circuli in the basal sector are generally double the number in the lateral sectors. The apical sector shows the venation formed by the disintegration of circuli. The ctenii are narrow, slightly curved, keeled and sharply pointed (Text-fig. 1b).

The smallest scales of the species obtainable was of 23 mm. long specimens (Text-fig. 3a). They are broader than long, the proportion of length to breadth being nearly 1 : 1.3. The nucleus is situated nearer the base than the apex, its distance from the apex being nearly 1.5 times its distance from the base. The number of circuli are more in the apical sector and there are no circuli in the lateral sectors. There are slight indications of the basal radii. The basal margin is entire at this stage.

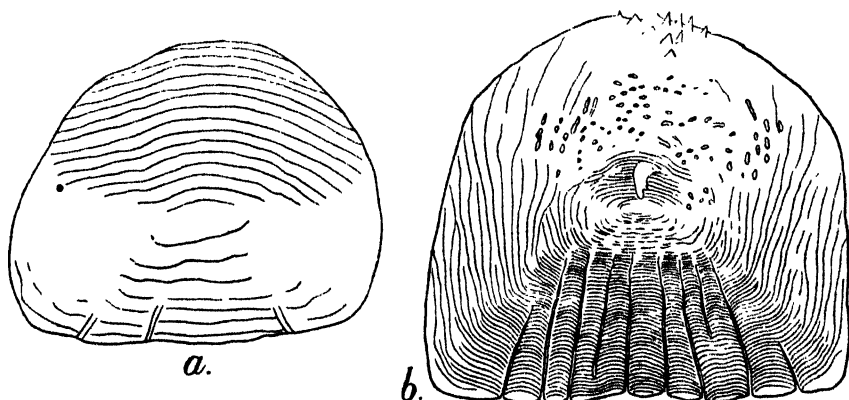


FIG. 3. a. The scale of a 23 mm. long specimen of *M. cephalus*. $\times 67\frac{1}{2}$.
b. The scale of a 70 mm. long specimen of *M. cephalus*. $\times 26$.

In the scales of 29 mm. long specimens the new circuli formed at the base can be seen to extend into the lateral sectors partly enclosing the juvenile scale. The proportion of length of the scale to its breadth has not changed but the nucleus has shifted a little towards the apex. Its distance from the apex is now only 1.3 times its distance from the base. The lateral line groove is also developed by now. The radii are well formed.

The scales of 45 mm. fish are more elongated and the proportion of length to breadth is only 1 : 1.2. The nucleus is now situated nearly in the middle of the scale.

In the scales of 60 mm. fish, the ctenii have begun to be formed and the apical circuli have started breaking up.

The scales of 70 mm. fish (Text-fig. 3b) show almost all the adult characters. There is a well-developed venation in the apical sector and certain portions of the lateral sectors. Some of the initial circuli remain in tact and this condition exists even in older scales. The nucleus is now nearer the apex than the base.

Mugil corsula Ham.

The major portion of the scale of *M. corsula* is hidden in the scale pocket, and there are 46-47 scales arranged along the mid-lateral line. A regular scale of adult *Corsula* is ctenoid and is conspicuously elongated (Plate XIX, fig. 3), the length being more than 1.5 times the breadth. The lateral margins are nearly straight and parallel and bend abruptly to form the apical margin. The baso-lateral angles are nearly right angles and the apico-lateral ones, obtuse. The nucleus is nearly circular in shape and is enclosed by the concentric initial circuli. It is situated very near the apex, its distance from the basal margin being about 5 times its distance from the apex. The basal sector is the largest and the circuli here are very densely arranged. Generally, every alternate or third circulus is continued into the lateral sectors. The basal and lateral sectors are granulated and the granulation is prominent in the region nearer the nucleus. The apical sector, which is nearly rhomboid in shape, is very clearly marked out and is fully occupied by the ctenii. The basal margin is undulate. There are 4-7 basal radii which converge towards the nucleus. The inter radial space is wide, and is contained 5-6 times in the length of the basal margin. The ctenii are long and pointed, the bases being rather stout (Text-fig. 1c).

The smallest specimens of *M. corsula* examined had a total length of 19 mm. and the scales of these are slightly broader than long (Text-fig. 4a). The nucleus is situated nearly at the middle of the scale. The initial circuli are fully formed and nearly circular in shape. The apical poles of the outer circuli are a little drawn out, giving a knob-like appearance. The true circuli of the lateral sectors extend up to the ctenal region. Generally every third circulus of the basal region is continued into the lateral sectors. The apical sector is very small and a few ctenii have already been formed. The basal margin is slightly undulate and the basal radii have been formed.

In 36 mm. specimens, the scales have become distinctly longer than broad, the proportion of breadth to length being nearly 1 : 1.1. The nucleus is now nearer the apex, its distance from the base being about 1.5 times its distance from the apex. More ctenii have been formed in the apical region, which has now increased in its extent. The lateral line groove has been formed.

In 46 mm. specimens, the scales have become more elongated, (Text-fig. 4b) the proportion of breadth to length being about 1 : 1.2. The nucleus has been shifted further towards the apex, and its distance from the base is now more than 1.75 times its distance from the apex. All the lateral circuli extend to the anterior border of the sector. The lateral line groove has become prominent.

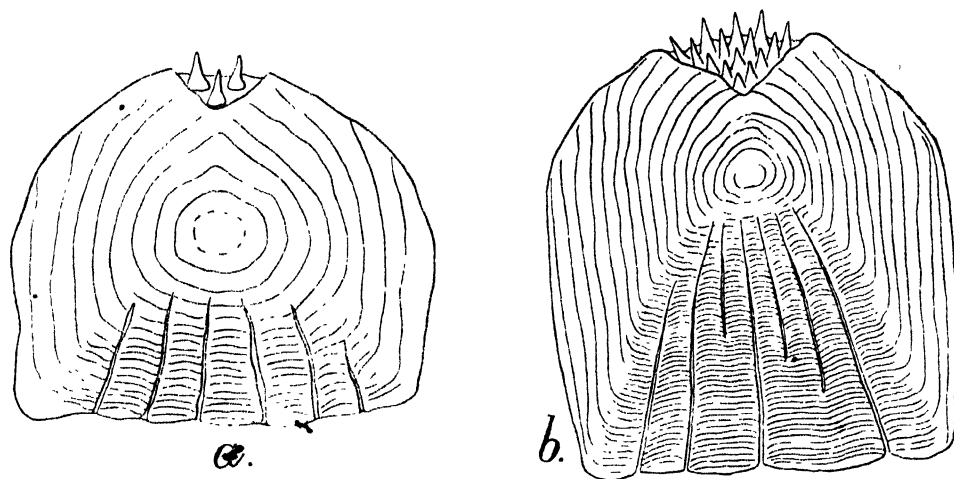


FIG. 4. *a.* The scale of a 19 mm. long specimen of *M. corsula*. $\times 50\frac{1}{2}$
b. The scale of a 46 mm. long specimen of *M. corsula*. $\times 34\frac{1}{2}$.

As the fish grows, the scale gets further elongated, and the nucleus becomes more and more apical in position. The adult sculpture is fully developed in the scales of 65 mm. specimens. Some of the initial circuli and true circuli of the lateral and basal sectors disintegrate with the growth of the scale, and give rise to the characteristic venation.

Mugil tade Forsk.

Regular scales of adult *M. tade* are ctenoid. They are rather large, and there are 30–35 of them on the midlateral line. The scales are longer than broad (Plate XIX, Fig. 4), the proportion of breadth to length being about 1 : 1.1. The apico-lateral angles are distinct and the baso-lateral angles are nearly right angles. The basal sector is the largest and the apical the smallest. The circuli are densely arranged in the basal sector. Generally, every second or third circulus of this sector is continued into the lateral sectors. The apical sector is very clearly marked out, and has ctenii and ctenobasii arranged on the marginal region, below which is seen the venation formed by the breaking up of the apical circuli. There are 5–8 basal radii which are arranged fan-wise. The interradii space is narrow and is contained 7–8 times in the length of the basal margin. The nucleus is apical in position, and its distance from the base is nearly two times its distance from the apex. It is enclosed by the initial circuli, which are nearly semicircular in shape. The ctenii (Text-fig. 1*d*) are stout and pointed.

The smallest specimen of *M. tade* procurable was 15 mm. in length, and the scales of these are cycloid and broader than long (Text-fig. 5*a*), the proportion being more than 1 : 1.2. The nucleus is situated nearly in the middle of the scale. The initial circuli are continuous, and the initial field elliptical in shape. The basal margin is undulate and the basal radii have begun to develop. The baso-lateral angles are right angles, and the apico-lateral angles are not distinct.

The scale remains cycloid and broader than long even in 24 mm. specimens. The nucleus is situated in the middle of the scale. The circuli in the basal sector are densely arranged and most of the circuli of the lateral sector stop short of the apical sector. The basal radii are more developed, and the lateral line groove has begun to form. Scales of 30 mm. specimens show indications of ctenii.

In the scales of 34 mm. specimens rows of long and sharp ctenii are well developed on the apical margin. The lateral line groove has become prominent.

Scales of 48 mm. specimens (Text-fig. 5b) have developed further, but they are still broader than long. The nucleus is now situated nearer the apex than the base, its distance from the base being about 1.5 times its distance to the apex. The apico-lateral angles are not yet distinct. All the lateral circuli do not extend to the margins, and the breaking up of circuli in the apical sector has begun.

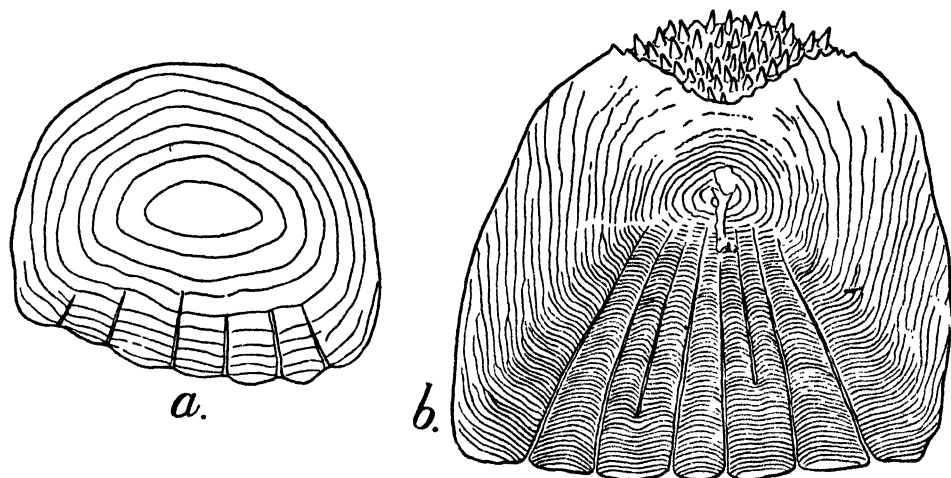


FIG. 5. a. The scale of a 15 mm. long specimen of *M. tade*. $\times 50\frac{2}{3}$.
b. The scale of a 48 mm. long specimen of *M. tade*. $\times 34\frac{2}{3}$.

Mugil parsia Ham.

A regular scale of *M. parsia* is ctenoid and is comparatively large in size (Plate XIX, Fig. 5). There are only 29-31 such scales on the midlateral line of the body. The scales are usually equal in length and breadth. The basal sector is the largest, and the baso-lateral angles are distinctly obtuse. The apico-lateral angles are clearly marked out. The basal margin is straight. There are 6-8 basal radii which converge towards the nucleus. The interradial space is contained 8-9 times in the length of the basal margin, which is undulate in outline. The nucleus is distinctly apical in position and its distance from the base is two times its distance from the apex. It is almost semi-circular in shape and is formed by the concentric initial circuli, the apical portions of which break up as the fish grows and give rise to the venation found on the apical region. The disintegrating ends of the lateral circuli also contribute to this formation. The ends of the lateral circuli nearer the margins tend to deflect outwards. The basal and lateral sectors are granulated and the granulations are more prominent in the lateral sectors. The ctenii are short and pointed (Text-fig. 1e).

The scales of the youngest specimens of this species procurable, which measured 13 mm., are cycloid and distinctly broader than long, the proportion of breadth to length being more than 1 : 1.3 (Text-fig. 6a). The basal margin is undulate in outline. The nucleus is situated in the middle of the scale and is nearly semi-circular in shape. The initial circuli have been fully formed and the true circuli and basal radii have begun to appear.

The scales of 25 mm. specimens do not show any great difference in shape. They are still broader than long, and are cycloid. More true circuli have developed. Scales of 29.5 mm. specimens show indication of the lateral line groove.

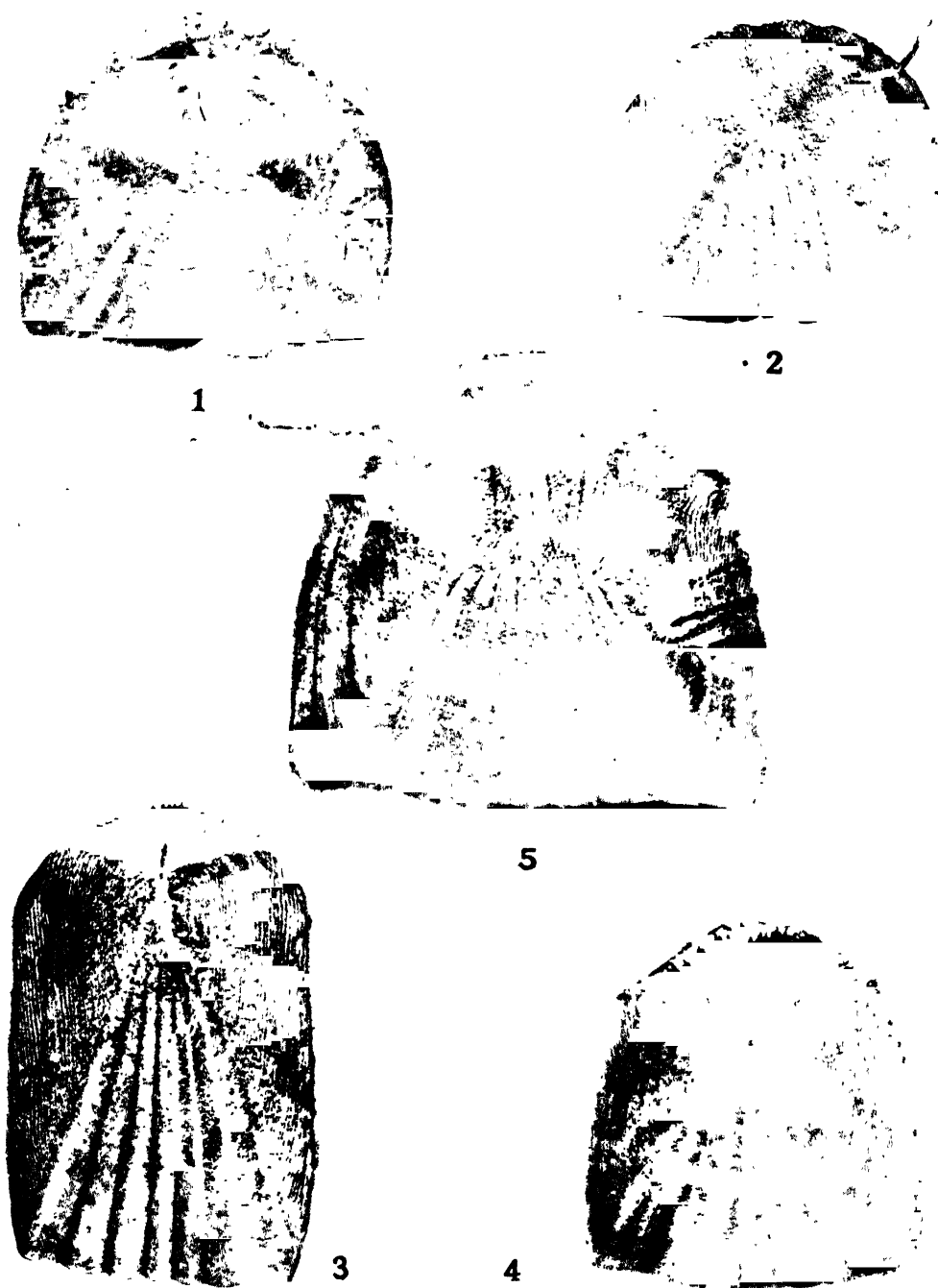


FIG. 1. Scale of *Mugil speigleri*, 13.5 cm. in total length. $\times 9$.
 FIG. 2. Scale of *M. cephalus*, 17.2 cm. in total length. $\times 9$.
 FIG. 3. Scale of *M. corsula*, 19.2 cm. in total length. $\times 9$.
 FIG. 4. Scale of *M. tade*, 13.5 cm. in total length. $\times 9$.
 FIG. 5. Scale of *M. parsia*, 15.0 cm. in total length. $\times 9$.

Scales of 35 mm. specimens (Text-fig. 6b) show much progress in development. They are only slightly broader than long now, and rows of ctenii have been formed at the apex. The nucleus has been shifted towards the apex, and is now situated nearer the apex than the base, its distance from the base being more than 1.4 times its distance from the apex. Some of the apical circuli have broken up. The newly formed lateral circuli do not extend to the apical region. The lateral line groove has been formed.

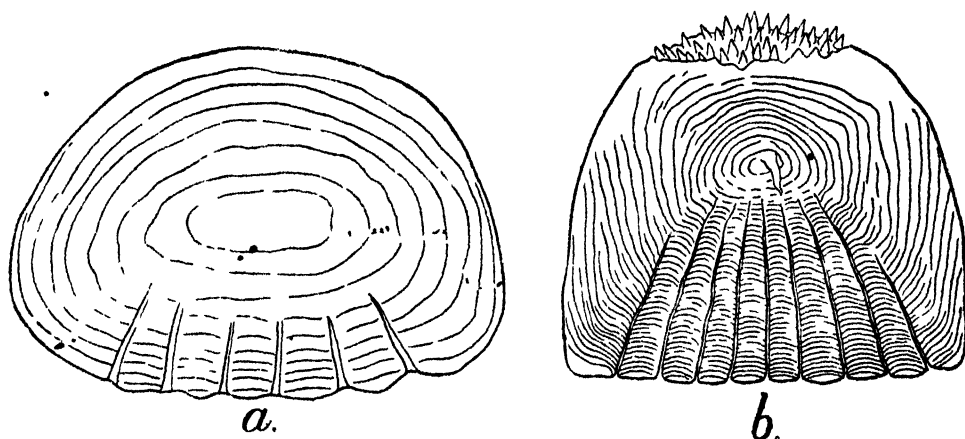


FIG. 6. a. The scale of a 13 mm. long specimen of *M. parria*. $\times 46\frac{1}{2}$
b. The scale of a 35 mm. long specimen of *M. parria*. $\times 34\frac{1}{2}$

The scales of specimens 43 mm. in length, show further progress in the venation on the apical region, but some of the initial circuli remain in tact. It is in scales of 53 mm. specimens that ctenobasii become distinguishable. At this stage the length and breadth of the scale have become nearly equal, and continues to be so in adults.

DISCUSSION.

Cockerell (1914) remarked that it is in the Mulletts that we meet with the typically ctenoid type of scale, as developed among the Acanthopterygians. But he was of the opinion that there is no evident connection between the scales of Mugils and those of the Atherenids. He had obviously examined only the scales of *Mugil curema* Cuv. & Val. (Cockerell, 1913) which he appears to have taken as the type for the genus. *M. curema* 'has large rounded scales, which are ctenoid, with a straight medially emarginate base, length about 9.5-10 mm.; breadth 11-11.5; basal radii few, crowded about the middle of the scale; nucleus apicad of middle; lateral circuli coarser than basal; apical margin minutely ctenoid; the apical region with the minutely imbricated structure of typical ctenoid scales.' He was thus evidently unaware of the wide variation of scale characters found in this genus. The present study shows that the Mugilid scale has evolved from the Atherenid one. This will become clear from an examination of the scale characters of *M. speigleri* which has the most primitive form of scale among the species studied. Its scales are cycloid, with basal radii, nearly rectangular nuclei and well-scalloped apical and basal margins. These characters are reminiscent of the Atherine scales (Cockerell, 1910 and 1914) and strongly suggest that the scale of *M. speigleri* is an intermediate form in the evolution of the typical ctenoid Mugil scales from that of the Atherines. Further, in the young of all the species studied, the scales are cycloid and broader than long, with the nucleus situated in the middle. Even in the highly elongated type of scale of *M. corsula* in which the nucleus is sub-apical

in position, the young ones have their scales broader than long, with the nucleus situated in the centre. In all these species, with the growth of the fish, the scales become less broad and finally become equal in length and breadth or longer than broad. The nucleus which is located at the border of the scale, pocket or just outside it, gets gradually shifted away from the centre and finally becomes apical in position. The early scales of all the species resemble very closely those of adult Atherines. These features, therefore, appear to be of strong phylogenetic significance. The scale characters of the atherine fishes from which the mullets have evolved are recapitulated during their development. Tims (1905) has similarly shown that in the development of scales in Gadidae, ontogeny recapitulates phylogeny. Discussing the affinities of Atherine larvae, Holt (1898) suggested that the Mugilidae have evolved from an Atherine-like type. The resemblances of the scale characters also lend strong support to this view.

Baudelot (1873), Tims (1905) and Hubbs (quoted by Lagler, *op. cit.*) regarded the cycloid scales as evolved from the ctenoid scales by the suppression of the spines. If this be so, we should expect this phylogenetic order to be recapitulated in the ontogeny of the fishes with cycloid scales. But it is in just the reverse order that the development takes place, and this would serve to prove the correctness of the view of Klaatch (1890), Duncker (1896), Creaser (1926), Lagler (*op. cit.*) and Ganguly and Mookerjee (*op. cit.*) that the ctenoid condition of a scale is an advance on the cycloid nature.

Hubbs (1921) considered Jacot's (*op. cit.*) discovery of the ctenoid nature of the scales of *M. cephalus* and *M. curema* as additional support to the view held by Jordan and Hubbs (1919) that the group Percesoces, comprising the *Mugilidae* and related families, is derived from the typical Acanthopterygii (which is characterised in part by ctenoid scales) and, hence, is not transitional between the cycloid scaled Malacopterygean fishes and the more specialised spiny-rayed types. But the present study has shown that all the mullets do not have ctenoid type of scales, and the nature of their scales do not lend support to the above theory.

Day (1878) remarked that in the marine forms of mullets the scales are usually cycloid or very feebly ctenoid, but in those species like *M. corsula*, *M. hamiltonii* and *M. cascasia* which entirely reside in fresh-water localities, the scales are strongly ctenoid suggesting thereby that there is some sort of a correlation between the habitats and the nature of the scales. None of the species dealt with in this paper are purely marine or fresh-water forms. All of them, including *M. corsula* which is generally considered as a fresh-water form, occur in the marine, estuarine and fresh-water conditions. But excepting *M. speigleri* all of them have ctenoid scales. It, therefore, appears improbable that the habitat has any bearing on the nature of the scales. Ryder (1893) considered that the arrangement and imbrication of the scales are determined by the actions of the segmentally arranged muscles of the body. Creaser (1926) and Taylor (1914) attributed the production of spines to the movements of the body. According to Duncker (1896) the ctenii are developed on a cycloid scale when it is raised out of the enclosing epithelium, so that a layer of ctenii-forming substance can be laid over the surface of the scale. The observations of Ganguly and Mookerjee (*op. cit.*) that the scales of the head and anal regions of *Sciaena coitor* are devoid of ctenii, was interpreted by them as proof of this theory. However, Mookerjee (1948) doubted the correctness of this view, though he did not indicate the reasons for doing so. The present study showed that the adults of *M. cephalus*, *M. parsia*, *M. corsula* and *M. tade* have ctenoid scales on all parts of the body except the snout and fin bases. If the above theory were correct, we should expect all the head-scales to be cycloid in all fish. The fact that this is not so, indicates that the cause for the formation of ctenii may not be the differential movements of the body as suggested by previous workers.

The study of the adult scales also helped to fix the identity of certain species. Day (1889) and Weber and de Beaufort (1922) considered *M. planiceps* Cuv. & Val.

synonymous with *M. tade* Forsk. Dr. Day's specimens of *M. planiceps* in the collections of the Zoological Survey of India, were examined and it was found that its scale characters are exactly the same as that of *M. tade* Forsk., indicating that they do not form different species. Whitehouse (1922) was of the opinion that *M. dussumieri* of Day is synonymous with *M. planiceps* Cuv. & Val. But the scale characters are quite different and they are decidedly separate species. Scales of authentically identified specimens of *M. dussumieri* Cuv. & Val. in the collections of the Zoological Survey of India were compared with scales of topotypes of *M. parsia* Ham., and it was found that the scale characters are identical. The scale of *M. dussumieri* Cuv. & Val. figured by Roxas (1934) in his review of the Philippine *Mugilidae* also resembles the scales of *M. parsia* Ham. Other taxonomic characters are also similar, and so it appears that they do not form separate species. I understand in this connection that an analysis of morphometric data made by Miss K. K. Sarojini also indicates that these two species are synonymous. According to international rules of nomenclature, the name *M. parsia* Ham. has priority and *M. dussumieri* Cuv. & Val. is, therefore, to be considered synonymous with it.

SUMMARY.

The importance of scale characters in the identification of Grey Mulletts (*Mugil* Linnaeus) is discussed. The scales of the *Mugil*s of Bengal show very great structural differences, which make their identification easy. A key for their identification, based on scale characters is given. The scale structures of the adults of the 5 species are described, and the development of these characters traced from the early stages. The affinities of the *Mugil*id scales are discussed. It is inferred that the ctenoid scales are developed from the cycloid type. The evidence offered by the scale characters regarding the evolution of *Mugil*s is also presented. The scale characters prove that *M. planiceps* Cuv. & Val. is synonymous with *M. tade* Forsk., and is different from *M. dussumieri* Cuv. & Val. It is probable that *M. dussumieri* Cuv. & Val. is synonymous with *M. parsia* Ham.

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THE ABUNDANCE DISTRIBUTION OF ELEMENTS.

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1. INTRODUCTION.

The problem of the relative abundances of elements and their isotopes has, in recent years, attracted considerable attention. Two essentially different hypotheses have been suggested for the synthesis of elements. In the equilibrium hypothesis, first put forward by Weizsäcker (1938), the elements are assumed to be formed as a result of thermodynamic equilibrium between elementary particles at some 'pre-stellar' stage when the temperature and density were high. The other hypothesis advanced by Alpher, Bethe and Gamow (1948) assumes the various nuclear species to have originated 'not as a result of an equilibrium corresponding to a certain temperature and density but rather as a consequence of a continuous building up process arrested by a rapid expansion and cooling of the primordial matter'.

Since Weizsäcker's work the equilibrium hypothesis has been considered by several investigators (1942-1947). Chandrasekhar and Henrich (1942) observe that it is possible to account satisfactorily for the observed abundances of elements from oxygen to sulphur under the physical conditions corresponding to

$$T = 8 \times 10^9 \text{ deg.}, \rho = 10^7 \text{ gm./c.c.}, \text{Log } n_p = 29.83, \text{Log } n_0 = 29.30$$

where n_p and n_0 denote respectively the proton and the neutron concentrations. The values of n_p and n_0 used in the computation of the mass-abundance curve were calculated by these authors from the equilibrium considerations of a nuclear assembly consisting of electrons, positrons, protons, neutrons and α -particles. In their discussion of such a simplified nuclear assembly Chandrasekhar and Henrich have not taken account of the degeneracy of the electrons¹ and the presence of the neutrinos.²

They have also ignored the presence of nuclei heavier than the α -particle in the assembly and no account has been taken of the contribution of the excited states³ of nuclei to the partition sum.

In the present paper we have first extended the discussion of the simplified assembly of Chandrasekhar and Henrich by taking account of the presence of neutrinos and the relativistic degeneracy of the electrons. We find that the effect of these two factors is to bring about a more rapid fall of the proton concentration than is given by the considerations of the simplified assembly.

We then study this nuclear assembly taking account of all the nuclei and the contributions of their excited states to the equations of nuclear equilibrium. These factors make the fall of proton concentration more rapid. Beskow and Treffenberg (1947) have also studied such a nuclear assembly using the method of Gibbs, whereas we have used here the method due to Darwin and Fowler.

¹ The non-relativistic degeneracy of the electrons in the nuclear assembly was first taken account of by Singwi and Rai (1946).

² This fact was pointed out by Klein (1946).

³ The contribution of these factors (both vibrational and rotational) becomes important in the case of heavy nuclei. We have derived expressions for these factors in sections 5 and 6.

The mass-abundance curve computed by us follows closely the Goldschmidt curve for elements up to Arsenic under the physical conditions:

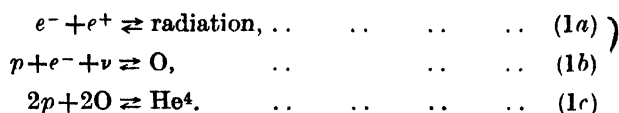
$$T = 8 \times 10^9 \text{ deg.}, \quad \text{Log } n_p = 29.1, \quad \text{Log } n_0 = 30.0$$

except for the elements Scandium, Vanadium and Titanium. No explanation is given for this anomaly. It has also been possible to account for the Oxygen-Helium and Oxygen-Iron discrepancies pointed out by Chandrasekhar and Henrich (1942). The equilibrium theory fails to account for the observed relative abundances of elements with mass number greater than 100.

2. SIMPLIFIED NUCLEAR ASSEMBLY.

In this section we first consider the equilibrium of a simplified assembly consisting of neutrons, protons, electrons, positrons and α -particles taking account of the presence of neutrinos and the degeneracy of the electrons and derive asymptotic expressions for the neutron-proton concentration in the two limiting cases: (i) when the electrons constitute a non-degenerate gas and (ii) when the electron gas is degenerate.

The fundamental reactions maintaining equilibrium are:



Since the assembly is electrically neutral we have

$$n^- = n^+ + n_p + 2n_2, \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

where n_p , n^- , n^+ and n_2 denote, respectively, the equilibrium concentrations of protons, electrons, positrons and α -particles. We do not take account of the hypothetical 'anti-protons'.

Case I.

$$\left. \begin{aligned} n^- &\gg n_p \\ n^- &\gg n_2 \end{aligned} \right\}$$

and

Equation (2) then gives $n^- \approx n^+$, i.e. the material density of the assembly is almost entirely due to the electron-positron pairs in thermal equilibrium. For temperatures greater than 4×10^9 deg. the electrons constitute a relativistic non-degenerate gas and (1a) gives for the electron or the positron concentration the expression

$$n^- = n^+ = 16\pi \left(\frac{kT}{ch} \right)^3 \exp. \left\{ -\frac{m_e c^2}{kT} \right\}, \quad \dots \quad \dots \quad (3)$$

where m_e is the mass of the electron and the other symbols have their usual meaning.

The equation governing the concentrations of free neutrons, protons, electrons and neutrinos is

$$\log \frac{n_p}{n_0} = - \log \frac{n^-}{16\pi \left(\frac{ch}{kT} \right)^3} - \log \frac{n_\nu}{16\pi \left(\frac{ch}{kT} \right)^3} + \frac{\Delta M c^2}{kT}, \quad \dots \quad \dots \quad (4)^1$$

where $\Delta M = M_0 - M_H$; M_0 and M_H being the masses of the neutron and the hydrogen atom respectively, and n_ν denotes the concentration of the neutrinos.

¹ We denote logarithm to the base e by log and to the base 10 by Log.

Since neutrinos and anti-neutrinos are in equilibrium with radiation the number of electrons is equal to the number of neutrinos. That this is so is evident from equation (3) since in the relativistic case the exponential term will be quite unimportant and the right side of the equation will, therefore, be independent of the mass of the particles. We shall, however, consider two cases: one in which there are no neutrinos and the other in which the number of neutrinos is equal to the number of electrons. With the latter assumption, we have from (3) and (4)

$$\frac{n_p}{n_0} = \exp. \left\{ (M_0 + m_e - M_p) c^2 / kT \right\}, \quad \dots \quad (5)$$

where M_p is the mass of the proton. Reaction (1c) gives

$$\frac{n_p^2 n_0^2}{n_2} = 2 \left(\frac{1}{4} \right)^{3/2} \left\{ 2 \left(\frac{2\pi M k T}{h^2} \right)^{3/2} \right\}^2 e^{-D_2^4 / kT}, \quad \dots \quad (6)$$

where $D_2^4 = c^2(2M_p + 2M_0 - M_2)$; M_2 is the mass of the α -particle.

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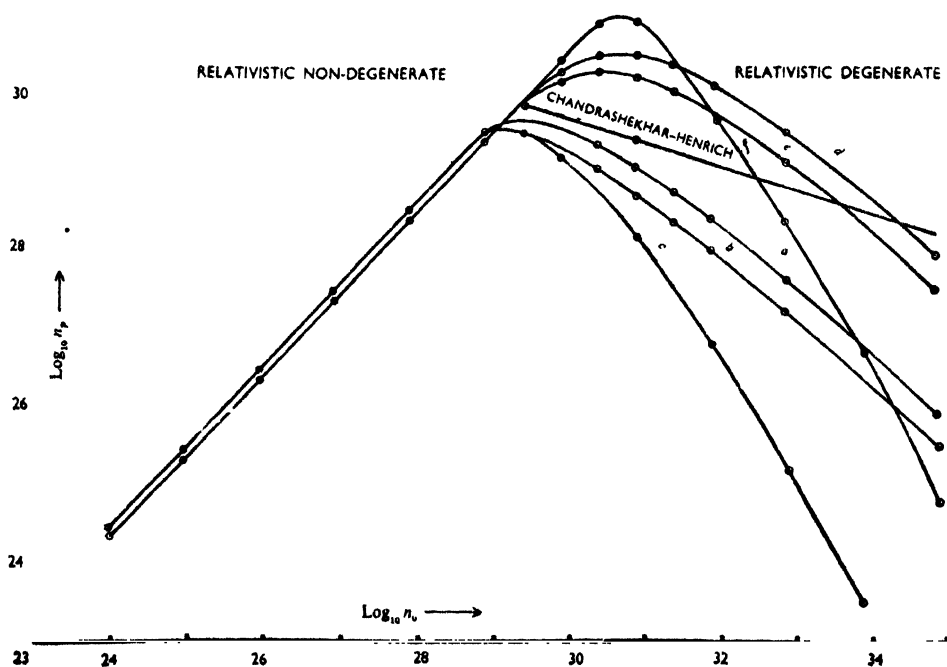


FIG. 1.

Curve a.	Simplified Assembly without Neutrinos.	} $T = 8 \times 10^9$ deg.
Curve b.	" " with " "	
Curve c.	Complete Assembly	
Curve d.	Simplified Assembly without Neutrinos.	} $T = 10^{10}$ deg.
Curve e.	" " with " "	
Curve f.	Complete Assembly	

Case II..

$$\left. \begin{array}{l} n^- \gg n^+, \\ \text{and } n^- \gg n_p. \end{array} \right\}$$

Equation (2) then gives $n^- \sim 2n_2$. In this case the electrons constitute a relativistic degenerate gas. Reaction (1b) gives

$$\log \frac{n_p}{n_0} = -\frac{ch}{kT} \left\{ \left(\frac{3n^-}{8\pi} \right)^{1/3} + \left(\frac{3n_p}{8\pi} \right)^{1/3} \right\} + \frac{\Delta M c^2}{kT} \dots \dots \dots (7)$$

Assuming $n^- = n_p$, and using the condition $n^- \approx 2n_2$ we have from (6) and (7)

$$\log \frac{n_p}{n_0} = -\frac{ch}{kT} \left(\frac{3}{\pi} \right)^{1/3} (n_p n_0)^{2/3} \left(\frac{2\pi M_p kT}{h^2} \right)^{-3/2} D_2^4 |kT + \frac{\Delta M c^2}{kT} \dots \dots (8)$$

If we neglect the presence of neutrinos there will be an additional factor 2 in the denominator of the first term on the right hand side of (8). In Table I, we give the proton concentration for arbitrary values of the neutron concentration as computed from (5) and (8) for temperatures $T = 10^{10}$ deg. and 8×10^9 deg. The results are also represented graphically in fig. 1. For the sake of comparison we have also given Chandrasekhar and Henrich's curve for $T = 8 \times 10^9$ deg. It will be observed that the effect of taking the relativistic degeneracy of the electrons into account is to bring about a more rapid fall of the proton concentration than when the electrons are considered to be non-degenerate.

TABLE I.

Log n_0 .	$T = 8 \times 10^9$ deg.			$T = 10^{10}$ deg.		
	Log n_p .			Log n_p .		
	Electrons non-degenerate.	Electrons Degenerate.		Electrons non-degenerate.	Electrons Degenerate.	
		Without neutrinos.	With neutrinos.		Without neutrinos.	With neutrinos.
26.0	26.47	..	..	26.37	..	..
27.0	27.47	..	..	27.37	..	..
28.0	28.47	..	..	28.37	..	..
29.0	29.47	..	..	29.37	..	..
30.0	..	29.45	29.16	..	30.25	30.16
30.5	..	29.28	28.95	..	30.48	30.29
31.0	..	29.02	28.66	..	30.50	30.22
31.5	..	28.71	28.33	..	30.35	30.03
32.0	..	28.36	27.97	..	30.11	29.76
33.0	..	27.59	27.18	..	29.47	29.08
35.0	..	25.91	25.49	..	27.89	27.48

3. THE COMPLETE NUCLEAR ASSEMBLY.

Strictly speaking we should include not only the α -particles but all the nuclei in the foregoing discussion. We should also take into account the partition function factors of the excited states of nuclei in the equilibrium equations—a fact which we have so far neglected. In what follows account has been taken of both these factors.

Equation (2) for the electrical neutrality of the assembly now becomes.

$$n^- = \sum_A n_A Z_A + n^+, \quad \dots \quad (9)$$

where Z_A denotes the charge-number of a nucleus of mass number A .

A nucleus of Z protons and N neutrons is formed according to

$$N + Z \rightleftharpoons A + \Delta E,$$

where A ($N + Z = A$) is the mass number of the nucleus formed and ΔE is the reaction energy. The equation governing the concentrations of neutrons, protons and nuclei is

$$n_A = \frac{n_0^N n_p^Z}{2^A} A^{3/2} \left(\frac{h^2}{2\pi M_p kT} \right)^{\frac{1}{2}(A-1)} \exp \left\{ \frac{\Delta E}{kT} \right\}, \quad \dots \quad (10)$$

where n_A denotes the concentration of the nucleus of mass-number A and ΔE is given by

$$\Delta E = (NM_0 + ZM_p - M_A)c^2.$$

Wherever the masses are not known accurately we use for ΔE the semi-empirical relation due to Weizsäcker¹

$$\frac{\Delta E}{kT} = -\frac{68.14A}{T} + \frac{954.5Z}{T} - \frac{954.5}{T} \frac{Z^2}{A} - \frac{179.1}{T} A^{2/3} - \frac{7Z^2 A^{-1/3}}{T} \quad \dots \quad (11)$$

where T is in units of 10^9 deg.²

In the calculations of this section (II) is assumed to give the binding energy of a nucleus of mass number A from $Z = 0$ to $Z = A$. This assumption implies an extrapolation going, indeed very far beyond the region known experimentally. It is not possible to justify this procedure theoretically but in the absence of any better data available, we shall be satisfied with (II).

If we take into account the vibrational and rotational states of nuclei an extra factor $\log \Sigma_\omega \Sigma_\nu$ is added to the exponential part in (10), where Σ_ω and Σ_ν represent, respectively, the rotational and vibrational partition function factors. For $A > 16$ (as shown in the sequel)

$$\log \Sigma_\omega \Sigma_\nu = -9.05 + \frac{66.83}{TA^{5/3}} + \frac{3}{2} \log T + \frac{5}{2} \log A - 0.14AT. \quad \dots \quad (12)$$

For $A < 16$ recourse has to be taken to numerical integration. Equation (10) now becomes

$$n_A = \frac{n_0^N n_p^Z}{2^A} A^{3/2} \left(\frac{h^2 \times 10^{-9}}{2\pi M_p kT} \right)^{\frac{1}{2}(A-1)} \exp \left\{ \log \Sigma_\omega \Sigma_\nu + \frac{\Delta E}{kT} \right\}. \quad \dots \quad (13)$$

From (11), (12) and (13) we have

$$\begin{aligned} \Sigma_A n_A Z_A = \sum_{A,Z} \left[\frac{A^4 T^{3/2} n_0^A}{2^A} \left(\frac{h^2 \times 10^{-9}}{2\pi M_p kT} \right)^{\frac{1}{2}(A-1)} \exp \left\{ -9.05 + \frac{66.83}{TA^{5/3}} + 0.14AT - \frac{68.14A}{T} \right. \right. \\ \left. \left. - \frac{179.1A^{2/3}}{T} \right\} \times Z_A \exp \left\{ -\frac{Z_A^2}{AT} (954.5 + 7A^{2/3}) + \frac{Z}{T} \left(954.5 + T \log \frac{n_p}{n_0} \right) \right\} \right]. \quad \dots \quad (14) \end{aligned}$$

¹ Nuclear Physics Tables, Mattauch and Flügge, 1946, p. 101.

² Henceforth, we shall always express T in units of 10^9 deg.

Consider now the summation

$$\begin{aligned}
 S &= \sum_{Z=0}^A Z \exp. \left\{ -\frac{Z^2}{AT} (954.5 + 7A^{2/3}) + \frac{Z}{T} \left(954.5 + T \log \frac{n_p}{n_0} \right) \right\} \\
 &= e^{\beta^2} \sum_{Z=0}^A Z \exp. \{ -(\alpha Z - \beta)^2 \} \\
 &= e^{\beta^2} \int_{-\beta}^{\alpha A - \beta} \frac{x + \beta}{\alpha^2} e^{-x^2} dx
 \end{aligned}$$

where

$$\text{and} \quad \left. \begin{aligned} \alpha^2 &= \frac{1}{AT} (954.5 + 7A^{2/3}) \\ 2\beta\alpha &= \frac{1}{T} \left(954.5 + T \log \frac{n_p}{n_0} \right) \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (15)$$

The limits in the above integration can be changed to $-\infty$ to $+\infty$ without affecting the value of the integration. We then have

$$S = \frac{\sqrt{\pi} \beta}{\alpha^2} e^{\beta^2} \quad \dots \quad \dots \quad \dots \quad (16)$$

Substituting (15) and (16) in (14) we have

$$\begin{aligned}
 \sum n_A Z_A &= \frac{\sqrt{\pi}}{2} T^{2e-0.05} \left(\frac{h^2 \times 10^{-9}}{2\pi M_p kT} \right)^{-3/2} \left(954.5 + T \log \frac{n_p}{n_0} \right) \\
 &\sum_A \left[A^{11/2} (954.5 + 7A^{2/3})^{-3/2} \exp. \left\{ A \left[\log \left(\frac{h^2 \times 10^{-9}}{2\pi M_p kT} \right)^{3/2} n_0 - \log 2 \right. \right. \right. \\
 &\quad \left. \left. \left. - \frac{68.14}{T} + 0.14T \right] \right\} \right. \\
 &\quad \left. \times \exp. \left\{ \frac{1}{T} \left[\frac{66.83}{A^{5/3}} - 179.1 A^{2/3} + \frac{A}{4} \frac{\left(954.5 + T \log \frac{n_p}{n_0} \right)^2}{(954.5 + 7A^{2/3})} \right] \right\} \right] \dots \quad (17)
 \end{aligned}$$

Since in the relativistic degenerate case $n^+ \ll n^-$ the neutrality condition (9) becomes

$$\sum n_A Z_A \approx n^- \quad \dots \quad \dots \quad \dots \quad (18)$$

If we neglect the presence of neutrinos we have, using (7) and (17) in (18)

$$-2.815 \times 10^{27} \left\{ 2.30 \log \frac{n_p}{n_0} - \frac{8.76}{T} \right\}^3 = 6.25 \times 10^{29} T^{1/2} \left(954.5 + 2.307 \log \frac{n_p}{n_0} \right).$$

$$\sum_{A=1}^{\infty} \left[A^{1/2} (954.5 + 7A^{2/3}) \exp. \left\{ A \left[\log (n_0 \times 7.35 \times 10^{-36}) - \frac{68.14}{T} - \log 2 + 0.14T \right] \right\} \right. \\ \left. \times \exp. \left\{ \frac{1}{T} \left(\frac{66.83}{A^{5/3}} - 179.1 A^{2/3} + \frac{A}{4} \frac{(954.5 + 2.307 \log \frac{n_p}{n_0})^2}{(954.5 + 7A^{2/3})} \right) \right\} \right] \dots \quad (19)$$

The above equation is balanced by trial and error for arbitrary values of n_0 for temperatures $T = 8 \times 10^9$ deg. and $T = 10^{10}$ deg. The results of such calculations are tabulated below:

TABLE 2

Log n_0 .	$T = 8 \times 10^9$ deg.	$T = 10^{10}$ deg.
	Log n_p .	Log n_p .
30	29.1	31.9
31	28.1	30.9
32	26.8	29.7
33	25.2	28.3
34	23.5	26.7
35	21.4	24.8
36	19.1	22.4

The above results are also represented graphically in fig. 1. We observe that the effect of including all the nuclei in the assembly is to bring about a more rapid fall of the proton concentration with increasing neutron concentration (beyond the proton maximum) than is given by the considerations of the simplified assembly of section 2. This result is not difficult to understand physically. As the neutron concentration increases more and more protons disappear from the assembly and go to form heavier and heavier nuclei. It can be easily seen from (19) that for $T = 8 \times 10^9$ deg. and $\log n_0 > 37$ matter will condense to nuclei of unlimited size.

4. THE THEORETICAL MASS-ABUNDANCE CURVE.

The relative concentrations of nuclei X_z^A and $X_{z'}^{A'}$ ($A' = A + \Delta p + \Delta v$, $z' = z + \Delta p$) is given by¹

$$\log \frac{n_{z'}^{A'}}{n_z^A} = \log \left(\frac{G_{z'}^{A'}}{G_z^A} \right) + \frac{3}{2} \log \frac{A'}{A} + \Delta p \left\{ \log n_p - 34.08 + \frac{3}{2} \log T \right\} \\ + \Delta v \left\{ \log n_0 - 34.08 + \frac{3}{2} \log T \right\} + \frac{4.692}{T} (D_{z'}^{A'} - D_z^A) \dots \quad (20)$$

¹ Chandrasekhar and Henrich, *loc. cit.*, equation (21), p. 293.

where G_Z^A denotes the total (vibrational plus rotational) partition function factor of the nucleus (A, Z), Δp and Δn the number of protons and neutrons, and D_Z^A the binding energy of the nucleus (A, Z) in milli-mass units. Wherever the masses are not known accurately we use the semi-empirical relation (II). Using (20) we have computed the relative abundances of various stable elements for temperatures $T = 8 \times 10^9$ deg. and $T = 10^{10}$ deg.

The results are given in Table 3 for $T = 8 \times 10^9$ deg. for which a better agreement with the observed values is obtained.

TABLE 3.

Element.	Z	A	$T = 8 \times 10^9$ deg. Log n_A —constant.	
			Calculated.	Observed.*
Helium	2	4	18.0	18.0
Carbon	6	12	14.6	13.7
Carbon	6	13	11.7	11.6
Nitrogen	7	14	10.9	13.1
Oxygen	8	16	14.0	14.0
Neon	10	20	11.6	12.7
Magnesium ..	12	24	12.0	12.1
Silicon	14	28	12.3	12.2
Sulphur	16	32	11.2	11.3
Argon	20	40	12.5	12.4
Scandium ..	21	45	11.6	7.2
Titanium ..	22	48	12.3	9.8
Vanadium ..	23	51	13.8	8.3
Iron	26	56	11.0	12.0
Cobalt	27	59	10.1	9.9
Copper	29	63	7.6	8.9
Gallium	31	69	6.2	7.0
Arsenic	33	75	9.0	7.5
Selenium ..	34	80	2.1	7.0

* These values were read from the graph given by Boskow and Treffenberg, *loc. cit.*

In fig. 2 we have compared the computed mass abundance curve with the empirical curve of Goldschmidt (1938). It is seen that the computed curve for $T = 8 \times 10^9$ deg. follows closely the empirical curve up to the element Arsenic under the conditions

$$\left. \begin{aligned} T &= 8 \times 10^9 \text{ deg.}, \\ \text{Log } n_p &= 29.1, \\ \text{Log } n_0 &= 30.0. \end{aligned} \right\} \dots \dots \dots (21)$$

5. DISCUSSION.

We have seen that the computed mass-abundance curve agrees fairly satisfactorily with the empirical curve under the conditions specified by (21), with the possible exception of the elements Scandium, Vanadium and Titanium. In the case of Vanadium the computed abundance is more than the observed value by a factor of 10^5 and in the case of Scandium this factor is 10^4 . In the case of A^{40} the coincidence between the observed and computed abundances is fortuitous because

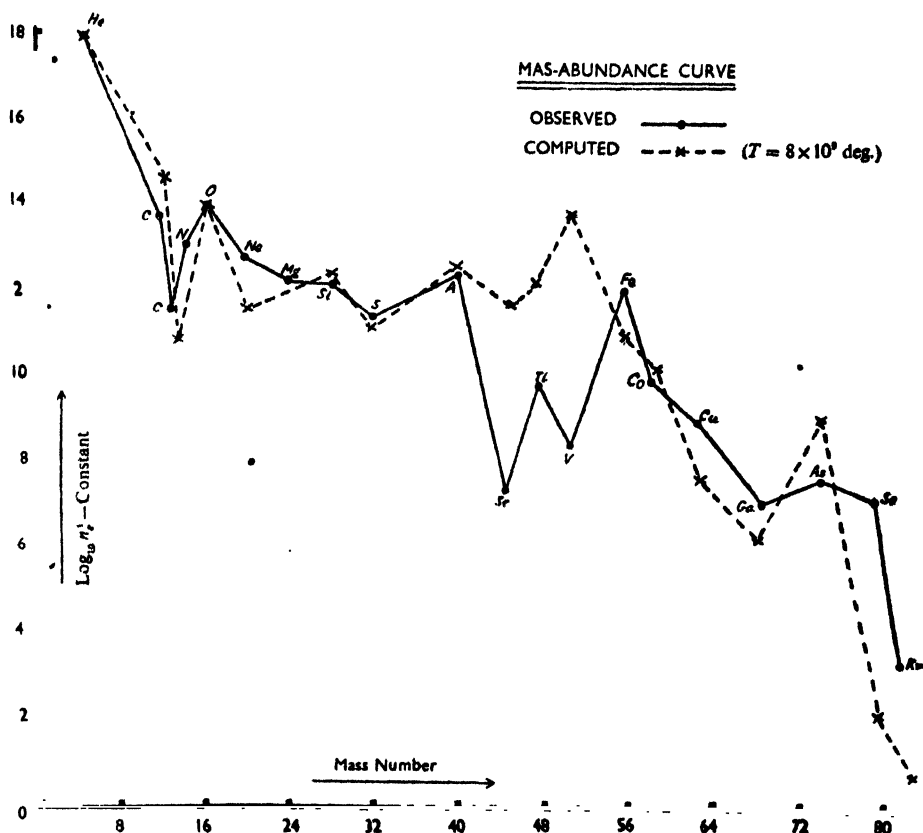


FIG. 2.

the abundance of A^{40} has, since its formation, increased, as pointed out by Poole (1948), by a factor of 300 owing to the transmutation of the unstable isotope K^{40} by k -capture. The masses of all these elements are known fairly accurately and the discrepancy between the observed and the calculated values could, therefore, not be due to an error in their mass determination. It has, however, not been possible to give an explanation of this discrepancy which, perhaps, has something to do with the peculiar nuclear structure of these elements.

The Oxygen-Helium discrepancy pointed out by Chandrasekhar and Henrich is nearly accounted for; our computed abundance $\text{He}^4 : \text{O}^{16}$ ratio is $10^4 : 1$, which is in good agreement with the known value. Again the $\text{O}^{16} : \text{Fe}^{56}$ ratio as computed by Chandrasekhar and Henrich is $1 : 10^{-10}$ whereas our value is $1 : 10^{-8}$, in much better accord with the known value $1 : 10^{-2}$.

Finally we may point out that as we approach elements heavier than Arsenic the computed abundances under the equilibrium conditions specified by (21) decrease rapidly. We find, however, that it is possible to account roughly for the observed abundances of elements from mass number 70 to mass number 100 under somewhat different conditions than those given by (21). For example we find that the abundance ratio $\text{Ru}^{102} : \text{Zr}^{90}$ agrees with the observed value for $\text{Log } n_0 = 30.8$ and $\text{Log } n_p = 28.3$. Beyond mass number 100 we do not get even a semblance of agreement. We, therefore, conclude that to account for the observed abundances of heavy elements we need distinctly different conditions from those needed for the

synthesis of light elements. Thus the equilibrium theory fails to account for the synthesis of heavy elements.

One very important feature of the abundance curve of Goldschmidt is that the abundance ratio for elements with mass number greater than 100 are almost constant with only a few fluctuations. A glance at the packing fraction curve will show that it will not be possible to account for the abundances of heavy elements on the basis of an equilibrium theory.

6. THE ROTATIONAL PARTITION FUNCTION FACTOR.

The rotational partition function factor of a nucleus of moment of inertia I is

$$Z_{\text{rot.}} = \sum_J (2J+1)^2 \exp. \{ -J(J+1)h^2/8\pi^2 IkT \}. \quad \dots \quad (22)$$

The moment of inertia I of a nucleus of mass number A is

$$I = \frac{2}{5} A m_H (R_0 A^{1/3})^2,$$

where $R_0 = 1.5 \times 10^{-13}$ cm, and m_H is the mass of the hydrogen atom. Putting $B = h^2/8\pi^2 IkT$ we have

$$Z_{\text{rot.}} = \sum_J 4(J+\frac{1}{2})^2 \exp. \{ -B(J+\frac{1}{2})^2 - \frac{1}{4} \}.$$

For $A > 4$

$$\begin{aligned} Z_{\text{rot.}} &\approx 4e^{B/4} \int_0^\infty x^2 e^{-Bx^2} dx \\ &\approx \sqrt{\pi} \frac{e^{B/4}}{B^{3/2}}. \end{aligned}$$

For purposes of computation

$$\text{Log } Z_{\text{rot.}} = -3.39 + \frac{29.02}{TA^{5/3}} + \frac{1}{2} \text{Log } T + \frac{1}{2} \text{Log } A. \quad \dots \quad (23)$$

7. THE VIBRATIONAL PARTITION FUNCTION FACTOR.

The vibrational partition function factor is

$$Z_{\text{vib.}} = \sum_{\text{excited states}} g_\nu e^{-E_\nu/kT} = 1 + \sum_{\text{excited states}} g_\nu e^{-E_\nu/kT}. \quad \dots \quad (24)$$

The summation on the right of (24) can be replaced by an integration if we use for the mean density of the higher vibrational states the expression given by Lier and Uhlenbeck (1937). According to them the number of nuclear levels between E_ν and $E_\nu + dE_\nu$ is

$$n(E_\nu) dE_\nu = \frac{1}{\sqrt{48} E_\nu} \cdot \exp. \left\{ \pi \sqrt{\frac{2A}{3\epsilon_0}} E_\nu \right\} dE_\nu,$$

where $\epsilon_0 = 10 \text{ MeV}$. Using the above relation we have

$$Z_{\text{vib.}} = 1 + \int_{\epsilon_0/24}^{E_0} \frac{1}{E \sqrt{48}} \exp. \left\{ -\frac{E}{kT} + \left(\frac{2\pi^2 A E}{3\epsilon_0} \right)^{1/2} \right\} dE, \quad \dots \quad (25)$$

where $\frac{\epsilon_0}{A}$ is taken as the energy difference between the lowest states of a nucleus of mass number A . E_0 is the binding energy of the nucleus in MeV . Putting

$$\frac{E}{kT} = x, \quad \frac{2\pi^2 A kT}{3\epsilon_0} = \delta,$$

we have for the integral in (25)

$$\begin{aligned} \frac{1}{\sqrt{48}} \int_{\pi^2/3\delta}^{E_0/kT} \frac{1}{x} \exp. \{ -x + \sqrt{\delta} x \} dx \\ = \frac{e^{\delta/4}}{2\sqrt{3}} \int_{\sqrt{\alpha} - \frac{\sqrt{\delta}}{2}}^{\sqrt{\beta} - \frac{\sqrt{\delta}}{2}} \frac{e^{-y^2} dy}{y + \frac{\delta}{2}}, \end{aligned}$$

where

$$\pi^2/3\delta = \alpha \text{ and } \frac{E_0}{kT} = \beta.$$

For $A > 16$ the value of the integral is

$$\frac{1}{2\sqrt{3}} e^{\delta/4}. \quad \dots \quad \dots \quad \dots \quad \dots \quad (26)$$

For purposes of computation we have (for $A > 16$)

$$\text{Log } Z_{\text{vib.}} = .0062AT - 0.54. \quad \dots \quad \dots \quad \dots \quad (27)$$

It is a pleasure to thank Prof. D. S. Kothari for many stimulating discussions.

SUMMARY.

In this paper the problem of the relative abundances of elements is re-examined on the basis of an equilibrium theory. The paper is divided into six sections:

Section 1 forms the introduction. Section 2 deals with the thermodynamic equilibrium of a simplified assembly consisting of neutrons, protons, electrons, positrons and α -particles; account is also taken of the degeneracy of the electrons and the presence of the neutrinos. Asymptotic expressions are derived for the neutron versus proton concentration in the two limiting cases of (i) non-degeneracy and (ii) degeneracy of electrons.

In section 3 we again consider the thermodynamic equilibrium of the assembly in which all elements are present and account is also taken, in the equilibrium equations, of the partition function factors of the excited states of nuclei.

It is found that the effect of including all the nuclei in the assembly is to bring about a more rapid fall of the proton concentration (beyond the proton maximum) with increasing neutron concentration than is given by the considerations of the simplified assembly of section 2. We use, throughout, the method of Darwin and Fowler.

Using results of section 3 we compute in section 4 the relative abundances of elements for the temperature $T = 8 \times 10^9$ degrees and find that the computed abundance curve agrees fairly satisfactorily with the empirical curve of Goldschmidt for elements up to mass number 70 under the conditions:

$$T = 8 \times 10^9 \text{ deg.}, \quad \text{Log } n_0 = 30.0, \quad \text{Log } n_p = 29.1$$

with the exception of the elements Scandium, Vanadium and Titanium. We find that the equilibrium theory fails completely to account for the abundances of heavy elements. In Section 5 we give a discussion of the results.

Finally in sections 6 and 7 we derive the 'Zustände' for the higher rotational and vibrational states of the nuclei.

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SOME OBSERVATIONS ON THE PALAEOGEOGRAPHY OF THE GARO-RAJMAHAL GAP AS EVIDENCED BY THE DISTRIBUTION OF MALAYAN FAUNA AND FLORA TO PENINSULAR INDIA.

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INTRODUCTION.

After going through the Symposium on 'Satpura Hypothesis of the distribution of Malayan Fauna and Flora to Peninsular India' (Hora *et al.*, 1949), Dr. Ernst Mayr very kindly favoured me with the following comments:—

'Three points seem important:

- (1) In view of the fact that the geological evidence for the recent date of the Garo-Rajmahal gap is very ambiguous, it is important to look for ecological factors that might have permitted transgap dispersal. Are the torrential fishes limited by oxygen in the water or by temperature or by absence of enemies? All three conditions might have been very different (in the low lands) at the height of the pluvial period.
- (2) In order to determine the length of the immigration period (from Assam to the Nilgiris) as well as the possible number of such periods, it is important to analyse and tabulate the taxonomic status of the Nilgiri isolates. What percentage is generically, specifically, subspecifically different? What percentage are still identical (taxonomically) with the Assam-Himalayan population? Obviously, rates of evolution are not the same in all genera, but such a tabulation would permit an approximation.
- (3) More attention should be paid to the eastern prong of colonization, going south through Bastar and the Eastern Ghats.

You have discovered a fascinating problem and I hope that your efforts for a final and complete solution will yield abundant results.'

In a recent review of the Symposium, Mayr (1950, p. 363) again referred to the significance of the Garo-Rajmahal Gap and stated:

'The geological evidence is ambiguous and seems to indicate a greater age for the Garo-Rajmahal Gap than postulated by Hora, although some geologists place it in the Pleistocene. Full agreement, however, exists in regard to the fact that during the Pleistocene the temperature was lower and the rainfall along these hills ranged much higher than is at present. The Zoogeographical importance of these hills is thus established, but whether or not complete continuity existed or was ever necessary remains to be determined. Throughout the Symposium little attention is paid to the possibility that animals can "jump" across considerable stretches of unsuitable terrain.'

In view of the considerations advanced above by Dr. E. Mayr, it seems necessary to re-examine the palaeogeography of the Garo-Rajmahal Gap from the late Pliocene to the end of the Pleistocene period. Except in the case of fishes, where three genera and two subgenera are different from the allied forms found in the Malayan Region, the Malayan isolates of other groups of animals found in the Peninsula have not

diverged generically or even subgenerically from the parental stocks. It can safely be assumed, therefore, that the bulk of this fauna migrated during the Pleistocene. The various levels of evolutionary divergences, ranging from endemic species to subspecific identity in the case of fish fauna are now under investigation by Mr. E. G. Silas. The question of the Eastern Ghats and the Orissa Hills as an alternate route of migration has been examined by Mr. A. G. K. Menon and a separate communication will appear on this subject shortly (*Proc. Nat. Inst. Sci. India*, in press).

CLIMATIC FLUCTUATIONS DURING THE PLEISTOCENE.

Peninsular India was not glaciated during the Pleistocene, nor the glaciers came anywhere close to it. However, it underwent climatic fluctuations alternating with the pluvial and arid periods. Along with temperature changes, the glacial ages were moist with intensified precipitation and interglacial periods were dry on account of lessened precipitation. The pluvial periods thus favoured the growth of thick forests even in the plains and made the dispersal of the moisture-loving forms possible over vast tracts of the country. Such conditions were more characteristic of the higher elevations and persisted at suitable altitudes even during the interglacial periods. This would account for the occurrence of the terrestrial Malayan fauna and flora on the tops of isolated hills of the Peninsula even today.

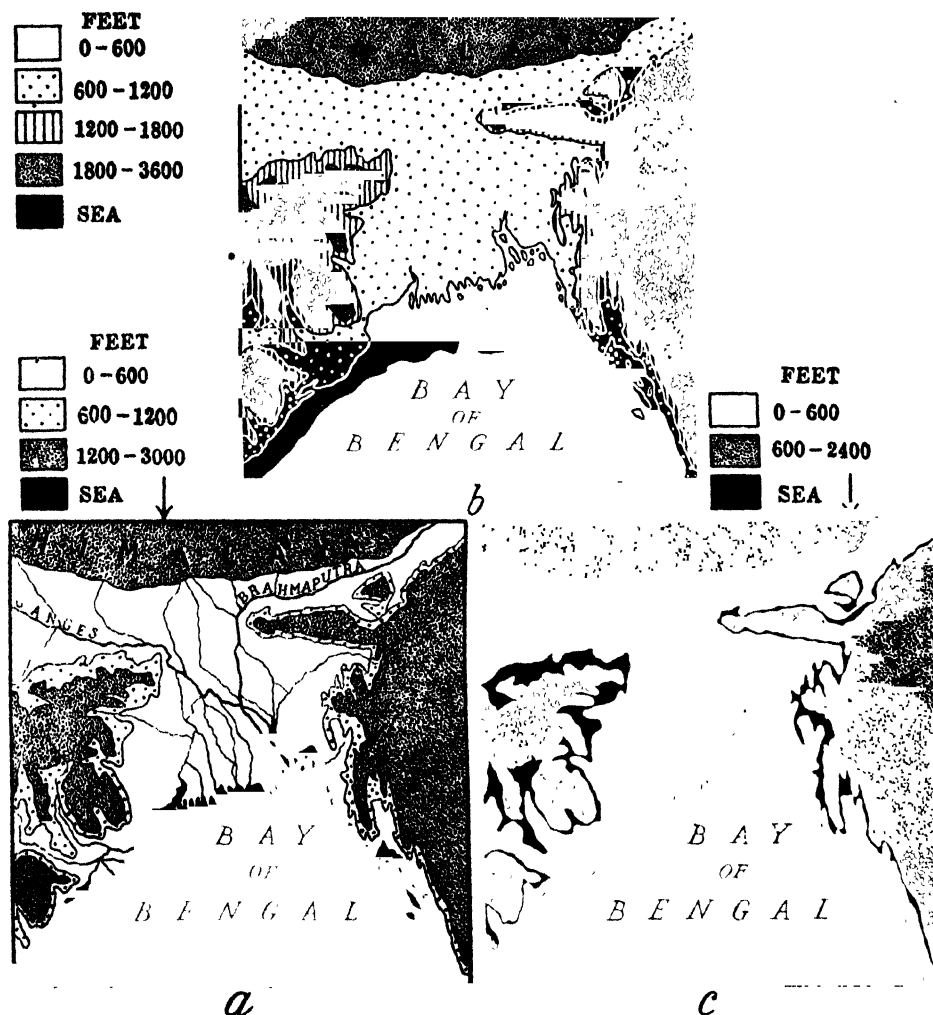
Under these conditions, during the pluvial periods, the terrestrial forms, like mammals, birds, etc., could have a very wide continuous distribution, but the same climatic conditions could not account for the dispersal of fishes and other aquatic fauna. There is no doubt that intensified precipitation produced more perennial streams and colder waters, containing more dissolved oxygen, were favourable for the life of torrential fishes. Rocky substratum is, however, necessary for their feeding, for their mouth parts are adapted for rasping off algal and other organic matter from rocks by applying their ventral surface very closely to them. During floods, the young of torrential fishes are sometimes washed down to the lower reaches of the rivers, but unless favourable ecological conditions are met with, they usually perish. Besides, for the dispersal of aquatic fauna, a continuity of water system is a very important factor and it is difficult to imagine how torrential fishes could ever have jumped across considerable stretches of unsuitable terrain. We have, therefore, to look for their dispersal not only a continuity of an elevated tract of country containing streams with rocky beds but also a mechanism for the commingling of waters of the streams in the east with those of the west, either through a series of river captures or tilting of drainage systems caused by earth movements.

EUSTATIC MOVEMENTS DURING THE PLEISTOCENE.

'It is known that, since the beginning of the Pleistocene, the sea-level has undergone repeated fluctuations. These were chiefly due to the formation of large ice-caps in the higher latitudes, resulting in a drop in sea-level, and to the more or less complete melting of the ice during the interglacials and after the last Glaciation, resulting in high sea-levels. The high sea-levels of the earlier phases were higher than the present (as much as 100 m. in the Sicilian phase, earliest Pleistocene). The standard succession for the phases of high and low sea-levels has been worked out in the Mediterranean, but evidence shows that it applies also to other parts of the earth, including South Africa and Australia. One is justified, therefore, in assuming that the same or very similar levels apply to the Malay Archipelago, though local evidence is still scanty' (Zeuner, 1941, pp. 117-118).

Though no information is yet available on the fluctuations in sea-levels in the seas of India, presumably they were not too different from those found in the Malay Archipelago. A good deal of work on ancient shore-lines has been done in the Pacific (Stearns, 1945; Cotton, 1947), but since it is assumed that much of this up and down of oceans is a worldwide phenomenon, the results may be equally applicable to the Indian Ocean.

In the accompanying diagram, I have shown in fig. *a* the present-day orographic features of the Garo-Rajmahal Gap and of the adjoining country; the same during a glacial age (fig. *b*) when the sea-level is supposed to have fallen by 600 feet; and the same during the interglacial period (fig. *c*) when the sea-level is supposed to have arisen by 600 feet. Lines of 600 feet rise or fall have been used, as lines of



Orographic features of the Garo-Rajmahal Gap.

a. Present-day condition; *b*. Condition during a glacial period (hypothetical); *c*. Condition during a much warmer interglacial period (hypothetical).

lesser elevation or depth are not at present available. These maps are purely hypothetical and do not in any way represent the actual eustatic movements of the Bay of Bengal. From what has been observed elsewhere in the world, these maps may approximate the actual conditions, provided tectonic movements had not interfered with them otherwise.

Figure *b* shows two features which are of great importance for ichthyogeography of this region. The main branch of the Ganges, which is now definitely shifting eastwards, in flowing over the new land exposed during glaciation, probably had a more westerly course and may have joined the Mahanadi and the latter may have some of its branches confluent with those of the Godavari. This would mean a similarity between the fish fauna of the lower reaches of the Ganges, the Mahanadi and the Godavari. In fact, this is so, as nearly 90 % of the fauna of the Mahanadi is Gangetic in origin and 30 % of the Godavari is allied to the Mahanadi fauna. But this migration of the fauna has not affected the hill-stream species as Mr. A. G. K. Menon has not found any Malayan element in the fish-fauna of the Mahanadi. A full account of this zoogeographical fact will be found in Mr. Menon's article referred to above.

The second important fact is that the present-day Gangetic Plain was 600 ft. higher than its present level. Relative to the glacial sea, the area of the Garo-Rajmahal Gap then became a plateau and hill-streams must have flowed over it. The precipitation would have increased and a thick forest must have covered this area. In fact, the conditions would have been similar to what they are today in the foot-hills of the Eastern Himalayas and it is likely that without any continuity of the Garo and Rajmahal Hills, this tableland, with its torrential streams, may have permitted the dispersal of hill-stream fishes across the present-day Garo-Rajmahal Gap.

Now let us consider figure *c* in which the lowlying areas of Bengal and of the Brahmaputra and the Ganges Valleys are shown as submerged during the interglacials. Unfortunately we have no evidence of such submergence, for if any existed it now lies buried deep under the alluvium. So far as Calcutta proper is concerned, in digging for the foundations of Gillander House in Clive Street, at a depth of 5 to 6 feet, an old oyster-bed was discovered. Dr. H. C. Ray, Malacologist of the Zoological Survey of India, has very kindly drawn up the following table for me showing the type of shells that were taken out, their distribution and habits.

*Table showing species of Molluscs taken from the Oyster-bed below
Clive Street, Calcutta.*

NAME.	DISTRIBUTION.	HABITS.
1. <i>Ostrea gryphoides</i> (Schlotheim).	<p>(a) Originally known from the Tertiary deposits of Siebenburgen in the province of Austria. But subsequently recorded from the Tertiaries of other countries, namely, Mount Laberon in Central France, Germany, Portugal, Spain, Algeria, Crete Island, neighbourhood of Tarsus in Asia Minor, Virginia, Torino. If Lamarck's <i>O. canadensis</i> from the Atlantic coast of north-east America is considered to be identical with it, as stated by Preston, Smith and Annandale, then its range would also extend further.</p> <p>(b) First instance of geological occurrence in India was recorded by Mr. Murray</p>	<p>Large living specimens of oysters, according to Major A. W. Alcock, F.R.S., are found in large numbers in the mud banks near the mouth of the channels of the Sunderbans. Their peculiarly elongated umbonal part and the ligamental pit enable the animals to raise their shells above the mud in which they would otherwise be buried. He also adds: 'Judging from their large size and robust appearance, it is improbable that these shells could have flourished much above low water mark, implying a relative position of the sea and land decidedly different from that obtaining at present.' In the Clive Street excavations the shells were found in a soil of sandy loam and mud.</p>

NAME.	DISTRIBUTION.	HABITS.
	<p>Stuart in sandstones overlying the Kama clay in the Henzada district of Burma.</p> <p>(c) Discovery of large shells of this fossil species in the excavations at Clive Street, Calcutta, certainly marks the survival of Miocene Oyster in recent seas. The existence of similar shells, however, in a living state in the Sunderban areas also lends strong support to this view. Besides these, there are shells of the same species in the Museum Collection from Mergui, Penang and Cutch. So, judging from these evidences of distribution of <i>O. gryphoides</i> in the far south-east Asia, one may possibly pin some faith in the prediction made by De Joubert (a foremost worker, 1774-1777, on the Tertiary Oysters of the Mediterranean countries representing Lamarck's <i>O. crassissima</i> and <i>gryphoides</i>, 1819) that 'their living analogues were to be found in the seas of the East Indies.'</p>	
2. <i>Telescopium telescopium</i> (Linn.).	<p>Mangrove swamps on the coasts of India, Gangetic delta, Irrawaddy delta, Reunion, Madagascar, Ceylon, Malay Archipelago, Singapore, Nicobars, Java, Sumatra, Timor, Madura, Celebes, New Guinea, Nias, Pulo-Panjang, Australia, Philippines, Japan. Round the environs of Calcutta, it is found quite common in ditches.</p>	<p>It is essentially an estuarine form. The ponderous nature of its trochiform shell makes the animal usually more sluggish in disposition, somewhat-like <i>Mitra mitra</i> (Linn.).</p>
3. <i>Indoplanorbis exustus</i> (Deshayes).	<p>Commonest of the large Planorbida of Indian fresh waters, having its range extended into the plains of India and Burma. Records are also known from Siam, Malay Peninsula, French Indo-China and Sumatra. It can also live in brackish water containing negligible percentage of salt.</p>	<p>It is usually found in fresh water tanks, pools, canals, etc., attached to aquatic vegetation and fallen leaves, etc. It can also endure brackish water containing more than about 1% of saline residue. During the floods in July, 1907, Annandale found this species migrating into certain brackish ponds at Port Canning on the River Matla (Ganges delta) from which it was usually absent. But when the salt became concentrated after the evaporation of water, these animals were found completely disappearing from these ponds.</p>

NAME.	DISTRIBUTION.	HABITS.
4. <i>Pila globosa</i> (Swainson).	One of the commonest freshwater molluscs, like <i>Viviparus bengalensis</i> (Lamarck), in Lower Bengal. But its range also extends to Orissa, Central Provinces, Rajputana and Bombay on the one hand and Bihar to United Provinces of Agra and Oudh on the other hand. It has not been known to occur in the Punjab, Sind, Madras and Burma. In the Punjab and Sind no living <i>Pila</i> is found at the present day, while in Madras and Burma the species is replaced by <i>virens</i> , <i>conica</i> and <i>theobaldi</i> .	This common Indian apple-snail is usually found floating on the surface of water among aquatic vegetation. It is not known to have been found in brackish water.
5. <i>Viviparus bengalensis</i> (Lamarck).	Widely distributed in fresh waters of Lower Bengal. Its range also extends to Bihar.	This well-known banded snail occurs in large numbers in freshwater tanks, pools, lakes, etc., which are very rich in aquatic vegetation and having muddy bottom. It is also known to occur in slightly brackish waters near Calcutta.
6. <i>Anomia achaea</i> (Gray).	A common species in the estuaries of the Ganges. But its wide range also extends to the Persian Gulf, Aden, Karachi, Bombay, Madras, Ceylon, Calcutta, Penang, Malacca, Kawa Bay and Amboina Anchorage.	This species is also often found in water that contains a sufficiently small proportion of salt to be called brackish.
7. <i>Monetaria moneta</i> (Linnaeus).	This money-cowry, as it has been commonly called, is essentially marine, being an inhabitant of clean salt water. Annandale writes: 'As, however, its shell was at one time used as money in Lower Bengal, its presence in the deposit at Clive Street, Calcutta, may be purely adventitious.' But its wide range extends from the Gulf of Oman and Strait of Hormuz, Red Sea on the west as far as Arakan on the east. Recently Abbott has recorded this species from the Cocos-Keeling Islands.	This well-known species occurs in the shallow waters of the sea, mostly in the coral reef areas.
8. <i>Ostrea cucullata</i> (Born).	This is a common brackish water species found widely distributed in the Indian Ocean, Gulf of Suez, Gulf of Aden, Red Sea, Bombay, Mada-	The species is found fixed on shells, stones, etc., encrusting the rocks below high- and low-water levels. It is also found on sand below mangrove trees.

NAME.	DISTRIBUTION.	HABITS.
	<p>gascar, Mozambique, Ceylon, Madras, Lake Chilka, Elphinstone Island Bay, Siam, Sumatra, Timor, Moluccas, Australia, Philippines, Japan. Dr. Annandale found this species in abundance in the Matla River, Port Canning, where the water contained only 2.5% of saline residue.</p>	

The 8 species of molluscs recorded in the table show that, when this bed was formed, estuarine conditions prevailed over the Calcutta area. Purely fresh water forms, *Indoplanorbis exustus*, *Pila globosa* and *Viviparus bengalensis*, may have been washed down from the neighbouring brackish or freshwater marshes.

Unless borings are taken in a number of places in the area of the Gap, it is difficult to say with certainty as to what happened during the interglacial periods in regard to the rise of the level of the sea. If there were no high ridges between the Garo and the Rajmahal Hills and if the sea-level had arisen as postulated here, considerable portions of the Ganges and the Brahmaputra valleys must have been submerged as shown in the figure.

Professor E. F. Zeuner was consulted with regard to the eustatic fluctuations in the Bay of Bengal and their likely effect on the Bengal Gap. He very kindly wrote to say that:

1. It is true that if conditions on land had remained entirely stable the lowlying areas of Bengal would have been submerged in the interglacials. Evidence for such short period submergence of flat country is very rare because the shallow deposits formed are very rapidly incorporated in the weathering soil forming after the following regression. They disappear, therefore, in most places in a very short time.
2. There is, however, the possibility that the Ganges depression is an area of continuous tectonic subsidence, i.e. it is possible that the sinking has continued, throughout the late Tertiary and Pleistocene and more or less kept pace in the filling process. In this case the gap was not necessarily inundated in high sea-level times. Since both alternatives are reasonable and there is no evidence proving that one of the two is false, it is impossible to have a definite opinion regarding your point.'

Van Bemmelen in his 'Geology of Indonesia' (p. 97) has also sounded a similar warning. He states:

- 'It appears from these critical remarks that it is a quite hazardous enterprise to try to correlate the Pleistocene stages of the orogenic belts of the Indian Archipelago with eustatic movements caused by fluctuations of the pleistocene glaciation.'

Dr. J. B. Auden has pointed out to me that along the mobile orogenic belts, in the most recent of which tectonic movements are still taking place, the changes in elevation due to orogenic forces may be far in excess of any possible change due to eustatic movements of sea-level, which are likely to have been of the order of 70 to 100 metres. Even in the now relatively stable peninsula of India, it is likely that broad warps are taking place, and have taken place, some going counter to the particular eustatic trend of the sea at the moment, and some of the same sign as the eustatic movement.

From the above discussion it will be seen that though it may be difficult to prove the submergence of the Gap area during the interglacials, there is enough evidence of the fall of the sea-level in the fish fauna of the Mahanadi and the Godavari and a

relative rise in the altitude of the Gap area with consequent heavier precipitation and formation of torrential streams in the region.

SUMMARY AND CONCLUSIONS.

In reviewing the Satpura Hypothesis (1950, p. 368-369), for the first time attention was paid to the relative height of the Garo-Rajmahal Gap during the glacial periods and its suitability for the dispersal of mountain species. In the Satpura Hypothesis, the main difficulty was to find out some means by which hill-stream fishes could spread from the Garo Hills to the Rajmahal Hills and hitherto attempt has been made to fill up the gap. Now it is postulated that a eustatic drop in the sea-level of 600 feet is likely to have had the same effect, both climatically and topographically. During each glacial age, favourable conditions for dispersal were established and thus waves of migration can now be dated to correspond with the Glacial Ages of the Pleistocene.

It is perhaps necessary to point out here that the river Ganges in its present form came into existence in the late Pleistocene, may be just before the last glacial epoch, and could not, therefore, have acted as a barrier for the dispersal of small torrential fishes. During the last Glacial period, parts of the Gangetic fauna probably became transferred to the Mahanadi over the newly exposed land.

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ON A TREATMENT OF IMPERFECT GASES AFTER FERMI'S MODEL (IV).¹

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INTRODUCTION.

In three previous papers (Dutta, 1947, 1948, 1951), the behaviour of the imperfect gases has been fully investigated by a new statistical method. The convenience and simplicity of the method lies in representing the state of a particle constituting the assembly, by a pair of representative points, one in the configurational space, and the other in the momenta space. The imperfections in gases are mainly due to two reasons, firstly owing to the finite size of particles, and secondly owing to the field of forces. The effect of finite size of particles in molecular theory of matter may be expressed as: the particles cannot approach infinitely close to each other, i.e. there is always a volume of exclusion about each particle within which no other particle can enter. Up to a first approximation, the volume of exclusion is taken as same. It has been shown in the previous papers (referred to above) that, for statistical consideration, in order to take this effect of finite size of particles into account, the configurational space is divided into cells, each of which has a volume equal to the rigid volume of exclusion of the particles, and the particles are supposed to be distributed in these cells according to a principle of exclusion, which has been formulated as: 'No more than one particle can come within a cell at the same instant. A cell may be vacant or may be occupied by only one molecule'. To take the effect of fields of forces, which may be due to an external field or to molecular interactions, into account, the configurational space is divided into potential energy layers prior to the division into cells. The distributions of particles in different layers and in different cells are calculated. The calculation of the partial thermodynamic probability in configurational space is entirely similar to the calculation of thermodynamic probability in Fermi-Dirac statistics. The partial thermodynamic probability for distributions in the momenta space has been calculated in the usual way after Planck and Lorentz. The results, obtained in the above manner, are found to be fairly good approximations to the experimental results.

In the paper, the above method has been suitably extended and applied to the statistical investigations for mixture of gases having two constituents. For convenience, the paper has been divided into three parts. In the first part, the method will be applied to the case of a mixture of gases of two types of molecules of finite size in absence of any field of force. In the second part, the method is further extended to include a Van der Waal field of force. The third part deals with fields of force of a general type. Here, for simplicity, we have treated the assembly of two components. As in the previous papers, for calculating the partial thermodynamic probability for configurational space, the configurational space will be supposed to be divided into layers of different potential energies. Then each layer

¹ The present paper (except part 3 of it) is a part of a thesis submitted for the D.Phil. (Science) degree of the Calcutta University.

is divided into cells of dimension equal to the rigid volume of exclusion of any type of molecules, and the distribution of representative points of particles in these cells is considered. After that, the unoccupied space in the configurational space will be again divided into cells of dimensions equal to the rigid volume of exclusion of particles of the other type, into which the distribution of the molecules of the second type will then be considered.

PART I. UNDER NO FIELD OF FORCES (EXTERNAL OR OF REACTIONS).

Description of the assembly: The assembly under consideration will be assumed to consist of two types of non-dissociating and non-associating molecules enclosed within a volume V .

Let the number of molecules of type (1) with mass m_1 be N_1 , and that of the other type (2) with mass m_2 be N_2 .

Let the volume of exclusion of particles of type (1) for distribution amongst themselves be b_1 and that of particles of type (2) amongst themselves be b_2 , while the volume of exclusion of molecules of one type in presence of molecules of other type be b_{12} . Now, at first, the total volume V is divided into cells of volume b_1 , the number of such cells being $\frac{V}{b_1}$. Then, the distribution of N_1 particles of type (1) is considered. After this distribution, the space left available for particles of type (2) is $V - N_1 b_{12}$ and this space is divided into cells of volume b_2 , the number of such cells being $\frac{V - N_1 b_{12}}{b_2}$. The distribution of molecules of the type (2) amongst these cells can now be considered.

Let a_i be the number of particles of type (1) with energy ϵ_i and a'_m that of the type (2) with energy η_m .

CALCULATIONS.

Then calculating the thermodynamic probability as proposed above, we have

$$W = \frac{\left(\frac{V}{b_1}\right)!}{N_1! \left(\frac{V}{b_1} - N_1\right)!} \cdot \frac{\left(\frac{V - N_1 b_{12}}{b_2}\right)!}{N_2! \left(\frac{V - N_1 b_{12}}{b_2} - N_2\right)!} \cdot \frac{N_1!}{\prod_i a_i!} \cdot \frac{N_2!}{\prod_m a'_m!}.$$

Now, as usual, using Stirling's formula for approximating factorials, and taking logarithm, we have

$$\begin{aligned} \log W = & \left(\frac{V}{b_1}\right) \log \left(\frac{V}{b_1}\right) - \left(\frac{V}{b_1} - N_1\right) \log \left(\frac{V}{b_1} - N_1\right) + \left(\frac{V - N_1 b_{12}}{b_2}\right) \log \left(\frac{V - N_1 b_{12}}{b_2}\right) \\ & - \left(\frac{V - N_1 b_{12}}{b_2} - N_2\right) \log \left(\frac{V - N_1 b_{12}}{b_2} - N_2\right) - \sum_i a_i \log a_i \\ & - \sum_m a'_m \log a'_m \quad \dots \quad \dots \quad \dots \quad \dots \quad (1) \end{aligned}$$

Now, this expression for $\log W$ should not be directly associated with the entropy by Boltzmann principle. The marking of certain type as the type (1) and the other as the type (2) is quite arbitrary and, has been done only for convenience of treatment. In the probability-expression related to the thermodynamic properties, characteristic quantities of both types of molecules should be involved in the same manner. It is thus essential to construct a probability function which will be

entirely symmetrical with regard to both types. But the expression (1) for the thermodynamic probability will be altered, if particles of the type (2) are distributed first, and then those of the type (1) instead of distributing molecules of type (1) and afterwards those of type (2) as considered in calculating the expression (1). In other words, the probability expression (1) as constructed, is unsymmetrical, and will be denoted as W_{12} . As similar expression calculated by distributing the type (2) first and the type (1) afterwards will be denoted by W_{21} . To write down a symmetrical expression for the probability, we shall adopt the device¹ frequently used in the quantum mechanics, and take

$$\log W = \frac{1}{2} (\log W_{12} + \log W_{21}). \quad \dots \quad (2)$$

This will be referred to, hereafter, as the principle of the symmetrisation of the thermodynamic probability.

Thus we have

$$\begin{aligned} \log W = & \left[\frac{1}{2} \left\{ \left(\frac{V}{b_1} \right) \log \left(\frac{V}{b_1} \right) - \left(\frac{V}{b_1} - N_1 \right) \log \left(\frac{V}{b_1} - N_1 \right) \right. \right. \\ & + \left(\frac{V - N_1 b_{12}}{b_2} \right) \log \left(\frac{V - N_1 b_{12}}{b_2} \right) + \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \log \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \\ & + \left(\frac{V}{b_2} \right) \log \left(\frac{V}{b_2} \right) - \left(\frac{V}{b_2} - N_2 \right) \log \left(\frac{V}{b_2} - N_2 \right) \\ & + \left(\frac{V - N_2 b_{12}}{b_1} \right) \log \left(\frac{V - N_2 b_{12}}{b_1} \right) - \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \\ & \left. \times \log \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \right\} \\ & - \sum_i a_i \log a_i - \sum_m a'_m \log a'_m \Big]. \quad \dots \quad (3) \end{aligned}$$

This is to be maximised subject to the following conditions

$$\left. \begin{aligned} \sum_i a_i &= N_1 \\ \sum_m a'_m &= N_2 \\ \sum_i a_i \epsilon_i + \sum_m a'_m \eta_m &= E \end{aligned} \right\} \quad \dots \quad (4)$$

where N_1 , N_2 , E and V are to remain constant during variation.

¹ The device, used here has also an interesting interpretation from the theory of probability. In the language of probability this may be expressed by saying that the selection of any type of particles for distribution at the first instance is of equal a priori probability, $\frac{1}{2}$. Here in considering distributions, so to say, it is supposed that the gas mixture is formed by transferring N_1 and N_2 particles of the constituent gases, one type after another from different spaces to the given space V . Then as any type of particle may be chosen first for distribution, so there are two different distributions. Each of these distributions is equally probable, and so has a probability $\frac{1}{2}$ of occurrence.

This gives in the usual way,

$$\left. \begin{aligned} a_i &= e^{-\lambda_1 - \mu \epsilon_i} \\ a'_m &= e^{-\lambda_2 - \mu \eta_m} \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

where λ_1 , λ_2 and μ are Lagrange's arbitrary constants to be adjusted.

Now, from equation (4), we have,

$$\begin{aligned} N_1 &= \sum_i a_i = e^{-\lambda} \sum_i e^{-\mu \epsilon_i} \\ &= e^{-\lambda} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-\mu \frac{p_x^2 + p_y^2 + p_z^2}{2m_1}} \cdot \frac{dp_x dp_y dp_z}{h^3/b} \\ \therefore \lambda_1 &= \log \left\{ \frac{b_1}{N_1 h^3} \left(\frac{2\pi m_1}{\mu} \right)^{\frac{3}{2}} \right\} \end{aligned} \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

and similarly,
$$\lambda_2 = \log \left\{ \frac{b_2}{N_2 h^3} \left(\frac{2\pi m_2}{\mu} \right)^{\frac{3}{2}} \right\}$$

Substituting the values of a_i 's and a'_m 's from the equations (5) and using Boltzmann hypothesis we have,

$$\begin{aligned} S &= K \left[\frac{1}{2} \left\{ \left(\frac{V}{b_1} \right) \log \left(\frac{V}{b_1} \right) - \left(\frac{V}{b_1} - N_1 \right) \log \left(\frac{V}{b_1} - N_1 \right) \right. \right. \\ &\quad + \left(\frac{V - N_1 b_{12}}{b_2} \right) \log \left(\frac{V - N_1 b_{12}}{b_2} \right) - \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \log \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \\ &\quad + \left(\frac{V}{b_2} \right) \log \left(\frac{V}{b_2} \right) - \left(\frac{V}{b_2} - N_2 \right) \log \left(\frac{V}{b_2} - N_2 \right) \\ &\quad + \left(\frac{V - N_2 b_{12}}{b_1} \right) \log \left(\frac{V - N_2 b_{12}}{b_1} \right) - \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \log \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \Big\} \\ &\quad \left. + \mu E + N_1 \log \left\{ \frac{b_1}{N_1 h^3} \left(\frac{2\pi m_1}{\mu} \right)^{\frac{3}{2}} \right\} + N_2 \log \left\{ \frac{b_2}{N_2 h^3} \left(\frac{2\pi m_2}{\mu} \right)^{\frac{3}{2}} \right\} \right]. \end{aligned}$$

By a well-known thermodynamic equation,

$$\frac{1}{T} = \left(\frac{\partial S}{\partial E} \right)_T = \mu k$$

we have

$$\mu = \frac{1}{kT} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

The entropy S and the thermodynamic function may now be written as

$$\begin{aligned} S &= k \left[\frac{1}{2} \left\{ \left(\frac{V}{b_1} \right) \log \left(\frac{V}{b_1} \right) - \left(\frac{V}{b_1} - N_1 \right) \log \left(\frac{V}{b_1} - N_1 \right) \right. \right. \\ &\quad \left. + \left(\frac{V - N_1 b_{12}}{b_2} \right) \log \left(\frac{V - N_1 b_{12}}{b_2} \right) - \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \log \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \right. \end{aligned}$$

$$\begin{aligned}
& + \left(\frac{V}{b_2} \right) \log \left(\frac{V}{b_2} \right) - \left(\frac{V}{b_2} - N_2 \right) \log \left(\frac{V}{b_2} - N_2 \right) \\
& + \left(\frac{V - N_2 b_{12}}{b_1} \right) \log \left(\frac{V - N_2 b_{12}}{b_1} \right) - \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \log \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \Big\} \\
& + \frac{E}{kT} + \frac{3}{2} N \log T + N_1 \log \left\{ \frac{(2\pi m_1 k)^{\frac{3}{2}}}{h^3} \cdot \frac{b_1}{N_1} \right\} \\
& + N_2 \log \left\{ \frac{(2\pi m_2 k)^{\frac{3}{2}}}{h^3} \cdot \frac{b_2}{N_2} \right\} \Big] \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (8)
\end{aligned}$$

and

$$\begin{aligned}
\psi = k \Big[\frac{1}{2} \Big\{ & \left(\frac{V}{b_1} \right) \log \left(\frac{V}{b_1} \right) - \left(\frac{V}{b_1} - N_1 \right) \log \left(\frac{V}{b_1} - N_1 \right) \\
& + \left(\frac{V - N_1 b_{12}}{b_2} \right) \log \left(\frac{V - N_1 b_{12}}{b_2} \right) - \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \log \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) \\
& + \left(\frac{V}{b_2} \right) \log \left(\frac{V}{b_2} \right) - \left(\frac{V}{b_2} - N_2 \right) \log \left(\frac{V}{b_2} - N_2 \right) \\
& + \left(\frac{V - N_2 b_{12}}{b_1} \right) \log \left(\frac{V - N_2 b_{12}}{b_1} \right) - \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \log \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \Big\} \\
& + \frac{3}{2} N \log T + N_1 \log \left\{ \frac{(2\pi m_1 k)^{\frac{3}{2}}}{h^3} \cdot \frac{b_1}{N_1} \right\} \\
& + N_2 \log \left\{ \frac{(2\pi m_2 k)^{\frac{3}{2}}}{h^3} \cdot \frac{b_2}{N_2} \right\} \Big] \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)
\end{aligned}$$

where

$$N = N_1 + N_2. \quad \dots \quad \dots \quad \dots \quad \dots \quad (10)$$

Then, from the well-known thermodynamic relation for pressure,

$$p = T \left(\frac{\partial \psi}{\partial V} \right)_T$$

we have

$$\begin{aligned}
p = kT \Big[\frac{1}{2} \Big\{ & \frac{1}{b_1} \cdot \log \left(\frac{V}{b_1} \right) - \frac{1}{b_2} \log \left(\frac{V}{b_1} - N_1 \right) + \frac{1}{b_2} \log \left(\frac{V - N_1 b_{12}}{b_2} \right) \\
& - \frac{1}{b_2} \log \left(\frac{V - N_1 b_{12}}{b_2} - N_2 \right) + \frac{1}{b_2} \log \left(\frac{V}{b_2} \right) - \frac{1}{b_2} \log \left(\frac{V}{b_2} - N_2 \right) \\
& + \frac{1}{b_1} \log \left(\frac{V - N_2 b_{12}}{b_1} \right) - \frac{1}{b_1} \log \left(\frac{V - N_2 b_{12}}{b_1} - N_1 \right) \Big\} \Big]
\end{aligned}$$

which gives

$$\begin{aligned}
p = \frac{NkT}{V} \cdot \frac{1}{2} \Big[& - \frac{V}{Nb_1} \Big\{ \log \left(1 - c_1 \frac{Nb_1}{V} \right) + \log \left(1 - c_1 \frac{Nb_1}{V - c_2 Nb_{12}} \right) \Big\} \\
& - \frac{V}{Nb_2} \Big\{ \log \left(1 - c_2 \frac{Nb_2}{V} \right) + \log \left(1 - c_2 \frac{Nb_2}{V - c_1 Nb_{12}} \right) \Big\} \Big] \dots \quad \dots \quad (11)
\end{aligned}$$

This may be called the Saha-Bose Equation of state for a mixture of gases, where

$$c_1 = \frac{N_1}{N}, \quad c_2 = \frac{N_2}{N} \quad \dots \quad \dots \quad \dots \quad \dots \quad (12)$$

Now for gases

$$\frac{V}{N_1 b}, \frac{V}{N_2 b} \gg 1$$

so that up to zeroth approximation, we have,

$$p = \frac{NkT}{V} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (13)$$

and up to the first approximation, we have,

$$\begin{aligned} p &= \frac{NkT}{V} \left[1 + c_1^2 \cdot \frac{1}{2} \frac{Nb_1}{V} + 2c_1c_2 \cdot \frac{1}{2} \frac{Nb_{12}}{V} + c_2^2 \cdot \frac{1}{2} \frac{Nb_2}{V} \right] \\ &= \frac{NkT}{V} \left[1 + \frac{c_1^2\beta_1 + 2c_1c_2\beta_{12} + c_2^2\beta_2}{V} \right] \\ &= \frac{NkT}{V-\beta} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (14) \end{aligned}$$

where

$$\beta_1 = \frac{1}{2}Nb_1, \quad \beta_2 = \frac{1}{2}Nb_2, \quad \text{and} \quad \beta_{12} = \frac{1}{2}Nb_{12} \quad \dots \quad \dots \quad (15)$$

and

$$\beta = c_1^2\beta_1 + 2c_1c_2\beta_{12} + c_2^2\beta_2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (16)$$

This is Van der Waal's Equation of state for a mixture of imperfect gases, in the absence of any field of force. Here the volume correction β has the same form as suggested by Lorentz (1927).

PART 2. MIXTURE OF GASES IN VAN DER WAAL'S FIELD OF FORCES.

Description: To consider the effect of Van der Waal's field of force, as shown previously (Dutta, II, 1947), it is sufficient to divide the physical space into two layers, one is the interior of volume V_1 , and the other is a boundary layer of volume V_2 where $V_2 \ll V_1$. Let the potential in the interior layer be $-\phi_1$, and that in the boundary layer $-\phi_2$. Let us consider an assembly consisting of N_1 and N_2 molecules of two different types of masses m_1 and m_2 respectively, enclosed in a volume V , where $V = V_1 + V_2$. It is assumed that there is no association or dissociation. Let, at any instant, N_{11} , N_{21} be the number of molecules of mass m_1 and m_2 in the interior of volume; and N_{12} and N_{22} be those in the boundary layer. Let a_i and a'_m have the same interpretation as before.

CALCULATION.

As in the earlier part of this chapter, the thermodynamic probability, calculated on distributing the molecules of the first type first and then those of the second type, is

$$\begin{aligned} W_{12} &= \frac{\left(\frac{V_1}{b_1}\right)!}{N_{11}! \left(\frac{V_1}{b_1} - N_{11}\right)!} \cdot \frac{\left(\frac{V_1 - N_{11}b_{12}}{b_2}\right)!}{N_{21}! \left(\frac{V_1 - N_{11}b_{12}}{b_2} - N_{21}\right)!} \cdot \frac{\left(\frac{V_2}{b_1}\right)!}{N_{12}! \left(\frac{V_2}{b_1} - N_{12}\right)!} \\ &\quad \cdot \frac{\left(\frac{V_2 - N_{12}b_{12}}{b_2}\right)!}{N_{22}! \left(\frac{V_2 - N_{12}b_{12}}{b_2} - N_{22}\right)!} \cdot \frac{N_1!}{\Pi a_i} \cdot \frac{N_2!}{\Pi a'_m} \end{aligned}$$

Taking logarithm after approximation by Stirling's formula, and symmetrising as in the previous case, we get,

$$\begin{aligned}
 \log W = & \left[\frac{1}{2} \left\{ \left(\frac{V_1}{b_1} \right) \log \left(\frac{V_1}{b_1} \right) - N_{11} \log N_{11} - \left(\frac{V_1}{b_1} - N_{11} \right) \log \left(\frac{V_1}{b_1} - N_{11} \right) \right. \right. \\
 & + \left(\frac{V_1 - N_{11} b_{12}}{b_2} \right) \log \left(\frac{V_1 - N_{11} b_{12}}{b_2} \right) - N_{21} \log N_{21} \\
 & - \left(\frac{V_1 - N_{11} b_{12}}{b_2} - N_{21} \right) \log \left(\frac{V_1 - N_{11} b_{12}}{b_2} - N_{21} \right) \\
 & + \left(\frac{V_1}{b_2} \right) \log \left(\frac{V_1}{b_2} \right) - N_{21} \log N_{21} - \left(\frac{V_1}{b_2} - N_{21} \right) \log \left(\frac{V_1}{b_2} - N_{21} \right) \\
 & + \left(\frac{V_1 - N_{21} b_{12}}{b_1} \right) \log \left(\frac{V_1 - N_{21} b_{12}}{b_1} \right) - N_{11} \log N_{11} \\
 & - \left(\frac{V_1 - N_{21} b_{12}}{b_1} - N_{11} \right) \log \left(\frac{V_1 - N_{21} b_{12}}{b_1} - N_{11} \right) \\
 & + \left(\frac{V_2}{b_1} \right) \log \left(\frac{V_2}{b_1} \right) - N_{12} \log N_{12} - \left(\frac{V_2}{b_1} - N_{12} \right) \log \left(\frac{V_2}{b_1} - N_{12} \right) \\
 & + \left(\frac{V_2 - N_{12} b_{12}}{b_2} \right) \log \left(\frac{V_2 - N_{12} b_{12}}{b_2} \right) - N_{22} \log N_{22} \\
 & - \left(\frac{V_2 - N_{12} b_{12}}{b_2} - N_{22} \right) \log \left(\frac{V_2 - N_{12} b_{12}}{b_2} - N_{22} \right) \\
 & + \left(\frac{V_2}{b_2} \right) \log \left(\frac{V_2}{b_2} \right) - N_{22} \log N_{22} - \left(\frac{V_2}{b_2} - N_{22} \right) \log \left(\frac{V_2}{b_2} - N_{22} \right) \\
 & + \left(\frac{V_2 - N_{22} b_{12}}{b_1} \right) \log \left(\frac{V_2 - N_{22} b_{12}}{b_1} \right) - N_{12} \log N_{12} \\
 & - \left(\frac{V_2 - N_{22} b_{12}}{b_1} - N_{12} \right) \log \left(\frac{V_2 - N_{22} b_{12}}{b_1} - N_{12} \right) \left. \right\} + N_1 \log N_1 \\
 & + N_2 \log N_2 - \sum_i a_i \log a_i - \sum_m a'_m \log a'_m \Big]. \dots \dots \dots (17)
 \end{aligned}$$

This is to be maximised subject to the following conditions:

$$\left. \begin{aligned}
 N_{11} + N_{12} &= N_1 \\
 N_{21} + N_{22} &= N_2 \\
 \sum_i a_i &= N_1 \\
 \sum_m a'_m &= N_2 \\
 (N_{11} m_1 + N_{21} m_2) \phi_1 + \sum_i a_i \epsilon_i + (N_{12} m_1 + N_{22} m_2) \phi_2 + \sum_m a'_m \eta_m &= E.
 \end{aligned} \right\} \dots (18)$$

where N_1, N_2, E, V_1, V_2 are to remain constant.

On using Lagrange's undetermined multipliers as usual we have,

$$\left. \begin{aligned} a_i &= e^{-\lambda_1 - \mu \epsilon_i} \\ a'_m &= e^{-\lambda_1 - \mu \eta_m} \\ \left(\frac{V_1}{N_{11}b_1} - 1 \right)^{\frac{1}{2}} \left(\frac{V_1 - N_{21}b_{12}}{N_{11}b_1} - 1 \right)^{\frac{1}{2}} \left(1 - \frac{N_{21}b_2}{V_1 - N_{11}b_{12}} \right)^{\frac{b_{12}}{2b_2}} &= e^{\nu_1 + \mu m_1 \phi_1} \\ \left(\frac{V_1}{N_{21}b_1} - 1 \right)^{\frac{1}{2}} \left(\frac{V_1 - N_{11}b_{12}}{N_{21}b_2} - 1 \right)^{\frac{1}{2}} \left(1 - \frac{N_{11}b_1}{V_1 - N_{21}b_{12}} \right)^{\frac{b_{12}}{2b_1}} &= e^{\nu_2 + \mu m_2 \phi_1} \\ \left(\frac{V_2}{N_{12}b_2} - 1 \right)^{\frac{1}{2}} \left(\frac{V_2 - N_{22}b_{12}}{N_{12}b_1} - 1 \right)^{\frac{1}{2}} \left(1 - \frac{N_{22}b_2}{V_2 - N_{12}b_{12}} \right)^{\frac{b_{12}}{2b_2}} &= e^{\nu_1 + \mu m_1 \phi_1} \\ \left(\frac{V_2}{N_{22}b_2} - 1 \right)^{\frac{1}{2}} \left(\frac{V_2 - N_{12}b_{12}}{N_{22}b_2} - 1 \right)^{\frac{1}{2}} \left(1 - \frac{N_{12}b_2}{V_2 - N_{22}b_{12}} \right)^{\frac{b_{12}}{2b_1}} &= e^{\nu_2 + \mu m_2 \phi_2} \end{aligned} \right\} \quad \dots (19)$$

Now in gases

$$\frac{N_{11}b_1}{V_1}, \frac{N_{11}b_{12}}{V_1}, \frac{N_{21}b_{12}}{V_1}, \frac{N_{21}b_2}{V_1}, \frac{N_{12}b_1}{V_2}, \frac{N_{12}b_{12}}{V_2}, \frac{N_{22}b_2}{V_2}, \frac{N_{22}b_{12}}{V_2} \ll 1.$$

Hence, up to the zeroth approximation we get

$$\begin{aligned} \frac{V_1}{N_{11}b_1} &= e^{\nu_1 + \mu m_1 \phi_1}, & \frac{V_1}{N_{21}b_2} &= e^{\nu_2 + \mu m_2 \phi_1} \\ \frac{V_2}{N_{12}b_1} &= e^{\nu_1 + \mu m_1 \phi_2}, & \frac{V_2}{N_{22}b_2} &= e^{\nu_2 + \mu m_2 \phi_2} \end{aligned}$$

or

$$\left. \begin{aligned} N_{11} &= \frac{V_1}{b_1} e^{-\nu_1 - \mu m_1 \phi_1}, & N_{21} &= \frac{V_1}{b_2} e^{-\nu_2 - \mu m_2 \phi_1} \\ N_{12} &= \frac{V_2}{b_1} e^{-\nu_1 - \mu m_1 \phi_2}, & N_{22} &= \frac{V_2}{b_2} e^{-\nu_2 - \mu m_2 \phi_2} \end{aligned} \right\} \quad \dots (20)$$

From (18), as before, we have,

$$\left. \begin{aligned} e^{-\nu_1} &= \frac{N_1 b_1}{V_1 e^{-\mu m_1 \phi_1} + V_2 e^{-\mu m_1 \phi_2}} \\ e^{-\nu_2} &= \frac{N_2 b_2}{V_1 e^{-\mu m_2 \phi_1} + V_2 e^{-\mu m_2 \phi_2}} \\ \lambda_1 &= \log \left\{ \frac{b_1}{N_1 h^3} \left(\frac{2\pi m_1}{\mu} \right)^{\frac{3}{2}} \right\} \\ \lambda_2 &= \log \left\{ \frac{b_2}{N_2 h^3} \left(\frac{2\pi m_2}{\mu} \right)^{\frac{3}{2}} \right\} \end{aligned} \right\} \quad \dots \dots \dots (21)$$

Now, as before (Dutta, II, 1948), since $V_2 < V_1$, we have approximately:—

$$\left. \begin{aligned} N_{11} &= N_1 \left(1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \\ N_{21} &= N_2 \left(1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \\ N_{12} &= N_1 \left(\frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \\ N_{22} &= N_2 \left(\frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (22)$$

where

$$\phi = \phi_2 - \phi_1 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (23)$$

Substituting these values for N_{11} , N_{12} , N_{21} , N_{22} , α_i 's and α_m 's from (19) and (16), we have

$$\begin{aligned} S = k \left[\frac{1}{2} \left\{ \left(\frac{V_1}{b_1} \right) \log \left(\frac{V_1}{b_1} \right) - 2N_1 \left(1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \log \left(N \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \right. \right. \\ \left. - \left(\frac{V_1}{b_1} - N_1 \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \log \left(\frac{V_1}{b_1} - N_1 \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \right. \\ \left. - 2N_2 \left(1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \log \left(N_2 \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \right. \\ \left. + \left(\frac{V_1}{b_2} - N_1 \frac{b_{12}}{b_2} \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \log \left(\frac{V_1}{b_2} - N_1 \frac{b_{12}}{b_2} \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \right. \\ \left. - \left(\frac{V_1}{b_2} - N_1 \frac{b_{12}}{b_2} \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] - N_2 \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \right. \\ \left. \times \log \left(\frac{V_1}{b_2} - N_1 \frac{b_{12}}{b_2} \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] - N_2 \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \right. \\ \left. + \left(\frac{V_1}{b_2} \right) \log \left(\frac{V_1}{b_2} \right) - \left(\frac{V_1}{b_2} - N_2 \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \right. \\ \left. \times \log \left(\frac{V_1}{b_2} - N_2 \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \right. \\ \left. + \left(\frac{V_1}{b_1} - N_2 \frac{b_{12}}{b_1} \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \log \left(\frac{V_1}{b_1} - N_2 \frac{b_{12}}{b_1} \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] \right) \right. \\ \left. - \left(\frac{V_1}{b_1} - N_2 \frac{b_{12}}{b_1} \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] - N_1 \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \right. \\ \left. \times \log \left(\frac{V_1}{b_1} - N_2 \frac{b_{12}}{b_1} \left[1 - \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right] - N_1 \left[1 - \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right] \right) \right. \\ \left. + \left(\frac{V_2}{b_1} \right) \log \left(\frac{V_2}{b_1} \right) - 2 \left(N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \log \left(N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \right. \\ \left. - \left(N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} - N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \log \left(N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} - N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \right. \\ \left. + \left(N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \log \left(N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \right\} \end{aligned}$$

$$\begin{aligned}
& - \left(\frac{V_2}{b_1} - N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \log \left(\frac{V_2}{b_1} - N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \\
& + \left(\frac{V_2}{b_2} - N_1 \frac{b_{12}}{b_2} \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \log \left(\frac{V_2}{b_2} - N_1 \frac{b_{12}}{b_2} \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \\
& - 2 \left(N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \log \left(N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \\
& - \left(\frac{V_2}{b_2} - N_1 \frac{b_{12}}{b_2} \frac{V_2}{V_1} e^{-\mu m_1 \phi} - N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \\
& \quad \times \log \left(\frac{V_2}{b_2} - N_1 \frac{b_{12}}{b_2} \frac{V_2}{V_1} e^{-\mu m_1 \phi} - N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \\
& + \left(\frac{V_2}{b_2} \right) \log \left(\frac{V_2}{b_2} \right) - \left(\frac{V_2}{b_2} - N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \log \left(\frac{V_2}{b_2} - N_2 \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \\
& + \left(\frac{V_2}{b_1} - N_2 \frac{b_{12}}{b_1} \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \log \left(\frac{V_2}{b_1} - N_2 \frac{b_{12}}{b_1} \frac{V_2}{V_1} e^{-\mu m_2 \phi} \right) \\
& + \left(\frac{V_2}{b_1} - N_2 \frac{b_{12}}{b_1} \frac{V_2}{V_1} e^{-\mu m_2 \phi} - N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \\
& \quad \times \log \left(\frac{V_2}{b_1} - N_2 \frac{b_{12}}{b_1} \frac{V_2}{V_1} e^{-\mu m_2 \phi} - N_1 \frac{V_2}{V_1} e^{-\mu m_1 \phi} \right) \Big\} \\
& + N_1 \log N_1 + N_2 \log N_2 + N_1 \lambda_1 + N_2 \lambda_2 + \mu E \\
& - \mu (N_{11} m_1 + N_{21} m_2) \phi_1 - \mu (N_{12} m_1 + N_{22} m_2) \phi_2 \Big]. \quad \dots \dots \dots (24)
\end{aligned}$$

From the well-known thermodynamic relation,

$$\frac{1}{T} = \left(\frac{\partial S}{\partial E} \right)_V = k\mu$$

we obtain,

$$\mu = \frac{1}{kT} \dots \dots \dots (25)$$

Again

$$\begin{aligned}
& (N_{11} m_1 + N_{21} m_2) \phi_1 + (N_{12} m_1 + N_{22} m_2) \phi_2 \\
& = (N_{12} m_1 + N_{22} m_2) \phi + (N_1 m_1 + N_2 m_2) \phi_1. \quad \dots \dots \dots (26)
\end{aligned}$$

Substituting these values and simplifying we have

$$\begin{aligned}
\psi = k \Big[& N_{11} \log \left(\frac{V_1}{b_1} \right) + N_{21} \log \left(\frac{V_1}{b_2} \right) - (N_{12} + N_{22}) \log \frac{V_2}{V_1} \\
& + N_{12} \log \left(\frac{V_2}{b_1} \right) + N_{22} \log \left(\frac{V_2}{b_2} \right) - N_1 \left(1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \log \left(1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \\
& - N_2 \left(1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \log \left(1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \\
& + \frac{1}{2} \left\{ - \left(\frac{V_1}{b_1} \right) \left(1 - \frac{N_1 b_1}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] \right) \log \left(1 - \frac{N_1 b_1}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] \right) \right.
\end{aligned}$$

$$\begin{aligned}
& + \left(\frac{V_1}{b_2} \right) \left(1 - \frac{N_1 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] \right) \log \left(1 - \frac{N_1 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] \right) \\
& - \left(\frac{V_1}{b_2} \right) \left(1 - \frac{N_1 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] - \frac{N_2 b_2}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] \right) \\
& \quad \times \log \left(1 - \frac{N_1 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] - \frac{N_2 b_2}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] \right) \\
& - \left(\frac{V_1}{b_2} \right) \left(1 - \frac{N_2 b_2}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] \right) \log \left(1 - \frac{N_2 b_2}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] \right) \\
& + \left(\frac{V_1}{b_1} \right) \left(1 - \frac{N_2 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] \right) \log \left(1 - \frac{N_2 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] \right) \\
& - \left(\frac{V_1}{b_1} \right) \left(1 - \frac{N_2 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] - \frac{N_1 b_1}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] \right) \\
& \quad \times \log \left(1 - \frac{N_2 b_{12}}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right] - \frac{N_1 b_1}{V_1} \left[1 - \frac{V_2}{V_1} e^{-\frac{m_1 \phi}{kT}} \right] \right) \\
& - \left(\frac{V_2}{b_1} \right) \left(1 - \frac{N_1 b_1}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \log \left(1 - \frac{N_1 b_1}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \\
& + \left(\frac{V_2}{b_2} \right) \left(1 - \frac{N_1 b_{12}}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \log \left(1 - \frac{N_1 b_{12}}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \\
& - \left(\frac{V_2}{b_2} \right) \left(1 - \frac{N_1 b_{12}}{V_1} e^{-\frac{m_1 \phi}{kT}} - \frac{N_2 b_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \\
& \quad \times \log \left(1 - \frac{N_1 b_{12}}{V_1} e^{-\frac{m_1 \phi}{kT}} - \frac{N_2 b_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \\
& - \left(\frac{V_2}{b_2} \right) \left(1 - \frac{N_2 b_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \log \left(1 - \frac{N_2 b_2}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \\
& + \left(\frac{V_2}{b_1} \right) \left(1 - \frac{N_2 b_{12}}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \log \left(1 - \frac{N_2 b_{12}}{V_1} e^{-\frac{m_2 \phi}{kT}} \right) \\
& - \left(\frac{V_2}{b_1} \right) \left(1 - \frac{N_2 b_{12}}{V_1} e^{-\frac{m_2 \phi}{kT}} - \frac{N_1 b_1}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \\
& \quad \times \log \left(1 - \frac{N_2 b_{12}}{V_1} e^{-\frac{m_2 \phi}{kT}} - \frac{N_1 b_1}{V_1} e^{-\frac{m_1 \phi}{kT}} \right) \} \\
& + N_1 \log \left\{ \frac{1}{N_1} \cdot \frac{b_1}{h^3} (2\pi m_1 kT)^{\frac{3}{2}} \right\} \\
& + N_2 \log \left\{ \frac{1}{N_2} \cdot \frac{b_2}{h^3} (2\pi m_2 kT)^{\frac{3}{2}} \right\} \\
& - (N_1 m_1 + N_2 m_2) \phi_1 \Big].
\end{aligned}$$

Expanding in series and retaining terms up to the first power of

$$\frac{V_2}{V}, \quad \frac{N_1 b_1}{V}, \quad \frac{N_1 b_{12}}{V}, \quad \frac{N_2 b_2}{V}, \quad \frac{N_2 b_{12}}{V},$$

we have, after simplification

$$\begin{aligned} \psi = Nk & \left[\log V - c_1 \frac{V_2}{V} \left(1 - e^{-\frac{m_1 \phi}{kT}} \right) - c_2 \frac{V_2}{V} \left(1 - e^{-\frac{m_2 \phi}{kT}} \right) \right. \\ & + 1 - \frac{c_1^2 \beta_1}{V} - \frac{c_2^2 \beta_2}{V} - \frac{2c_1 c_2 \beta_{12}}{V} + \frac{3}{2} \log T \\ & + c_1 \log \left\{ \frac{(2\pi m_1 k)^{3/2}}{h^3} \right\} + c_2 \log \left\{ \frac{(2\pi m_2 k)^{3/2}}{h^3} \right\} \\ & \left. - (c_1 m_1 + c_2 m_2) \frac{\phi_1}{kT} - c_1 \log c_1 - c_2 \log c_2 - \log N \right] \quad \dots \quad (27) \end{aligned}$$

where N , c_1 , c_2 , β_1 , β_2 , β_{12} have the same interpretation as given by (11).

The term $-c_1 \log c_1 - c_2 \log c_2$ is the usual Gibbs term in the expressions for entropy and free energy for a mixture of gases. Then by the usual thermodynamic relation we calculate,

$$\begin{aligned} p &= T \left(\frac{\partial \psi}{\partial V} \right)_T \\ &= \frac{NkT}{V} \left[1 + \frac{c_1^2 \beta_1 + 2c_1 c_2 \beta_{12} + c_2^2 \beta_2}{V} - \frac{(c_1 m_1 + c_2 m_2)}{kT} \left(\frac{\partial \phi}{\partial V} \right)_T \right. \\ &+ \left\{ \left(\frac{\partial V_2}{\partial V} \right)_T - \frac{V_2}{V} \right\} \left\{ 1 - \left(c_1 e^{-\frac{m_1 \phi}{kT}} + c_2 e^{-\frac{m_2 \phi}{kT}} \right) \right\} \\ &\left. - \frac{V_2}{kT} \left(c_1 m_1 e^{-\frac{m_1 \phi}{kT}} + c_2 m_2 e^{-\frac{m_2 \phi}{kT}} \right) \left(\frac{\partial \phi}{\partial V} \right)_T \right], \end{aligned}$$

so that,

$$p + \frac{\alpha}{V^2} = \frac{NkT}{V} \left[1 + \frac{c_1^2 \beta_1 + c_2^2 \beta_2 + 2c_1 c_2 \beta_{12}}{V} \right]$$

or simply

$$\left(p + \frac{\alpha}{V^2} \right) (V - \beta) = NkT \quad \dots \quad (28)$$

where

$$\beta = c_1^2 \beta_1 + c_2^2 \beta_2 + 2c_1 c_2 \beta_{12} \quad \dots \quad (16)$$

and

$$\begin{aligned} \alpha &= NkT \left[V_2 \frac{c_1 m_1 + c_2 m_2}{kT} \left(\frac{\partial \phi_1}{\partial V} \right) + \frac{V_2 \cdot V}{kT} \left(c_1 m_1 e^{-\frac{m_1 \phi}{kT}} + c_2 m_2 e^{-\frac{m_2 \phi}{kT}} \right) \left(\frac{\partial \phi}{\partial V} \right)_T \right. \\ &\left. + V \left\{ \left(\frac{\partial V_2}{\partial V} \right)_T - \left(\frac{V_2}{V} \right) \right\} \left\{ 1 - \left(c_1 e^{-\frac{m_1 \phi}{kT}} + c_2 e^{-\frac{m_2 \phi}{kT}} \right) \right\} \right] \quad \dots \quad (29) \end{aligned}$$

Comparing the equations (16) and (29) with that given by Lorentz (1927), we find that so far as the volume correction β is concerned, our form is in exact agreement with that obtained by Lorentz, though the pressure correction α , given above, is in somewhat different form. The dependence of α on T in our form is usually thought necessary for application of the formulae to a wide range of (temperature) data.

The expression for α as given by Lorentz (1927) can be very easily deduced from our α in the same manner as shown elsewhere (Dutta, II, 1947). As before, we shall take

$$\begin{aligned}\phi_1 &= \left(\frac{N_{11}m_1}{V} + \frac{N_{21}m_2}{V} \right) c', \\ &= \frac{N}{V} \left[c_1 m_1 \left\{ 1 + \frac{V_2}{V} \left(1 - e^{-\frac{m_1 \phi}{kT}} \right) \right\} + c_2 m_2 \left\{ 1 + \frac{V_2}{V} \left(1 - e^{-\frac{m_2 \phi}{kT}} \right) \right\} \right] \end{aligned}$$

and

$$\phi = \phi_2 - \phi_1 = \left(\frac{N_{12}m_1}{V_2} + \frac{N_{22}m_2}{V_2} \right) c'' - \left(\frac{N_{11}m_1}{V_1} + \frac{N_{21}m_2}{V_1} \right) c',$$

where c'' and c' have meanings similar to those used in a previous paper (Dutta, II, 1947).

Now, as

$$\frac{V_2}{V} < 1$$

and also, from the dimensional considerations (cf. Dutta, II, 1947) we have

$$V_2 \propto V^{2/3}.$$

Hence,

$$\left(\frac{\partial V_2}{\partial V} \right)_T \cong \frac{2}{3} \frac{V_2}{V} < 1.$$

Thus, we may write, approximately,

$$\begin{aligned}\phi_1 &= - \frac{N}{V} (c_1 m_1 + c_2 m_2) c', \\ \phi &= - \frac{N}{V} \left\{ \left(c_1 m_1 e^{-\frac{m_1 \phi}{kT}} + c_2 m_2 e^{-\frac{m_2 \phi}{kT}} \right) c'' - (c_1 m_1 + c_2 m_2) c' \right\}.\end{aligned}$$

and

$$\begin{aligned}\left(\frac{\partial \phi_1}{\partial V} \right)_T &= \frac{N}{V^2} (c_1 m_1 + c_2 m_2) c', \\ \left(\frac{\partial \phi}{\partial V} \right)_T &= \frac{N}{V^2} \frac{\left\{ \left(c_1 m_1 e^{-\frac{m_1 \phi}{kT}} + c_2 m_2 e^{-\frac{m_2 \phi}{kT}} \right) c'' - (c_1 m_1 + c_2 m_2) c' \right\}}{1 - \frac{N}{V} \left(c_1 m_1^2 e^{-\frac{m_1 \phi}{kT}} + c_2 m_2^2 e^{-\frac{m_2 \phi}{kT}} \right) 1/kT}.\end{aligned}$$

(correct up to 1st order).

Substituting these in the expression for α and neglecting all other terms, we have ultimately

$$\begin{aligned}\alpha &= N^2(c_1m_1+c_2m_2)^2c' \\ &= N^2(c_1^2m_1^2c'+2c_1c_2m_1m_2c'+c_2^2m_2^2c') \\ &= c_1^2\alpha_1+2c_1c_2\alpha_{12}+c_2^2\alpha_2\end{aligned}\left.\begin{array}{l} \\ \\ \end{array}\right\} \text{where} \quad \left.\begin{array}{l} \alpha_1 = N^2m_1^2c', \alpha_{12} = N^2m_1m_2c', \alpha_2 = N^2m_2^2c'. \end{array}\right\} \dots \dots (30)$$

This is identical with the expression for α given by Lorentz (1927).

PART 3. MIXTURE OF GASES UNDER ANY FIELD OF FORCES.

After the success of our method for an assembly composed of two types of molecules under the field of Van der Waal's forces, the generalisation of the method for any field of force appears to be called for. Now, the behaviour of an assembly of particles of two types under a field of force of general type will be considered. Of course, a simple restriction on the nature of the field of force will be imposed. The field of force assumed, is to be conservative and to have such a slow gradient that the change in magnitude of the field within a length of molecular dimension may be ignored. Obviously, this will not materially restrict the range of applicability of this method, since the gradient of fields of actual interest with exception of Van der Waal's field of forces may be assumed to satisfy the above restriction.

DESCRIPTION OF THE ASSEMBLY.

The assembly under consideration is assumed to consist of N_1 particles of mass m_1 and N_2 of mass m_2 enclosed in a volume V . Let the rigid volume of exclusion of particles of mass m_1 amongst themselves be b_1 that of mass m_2 be b_2 and that of particles of different types b_{12} .

For considering the distribution in the configurational space for any field of force, as shown previously (Dutta, III, 1951), the total volume of the physical space is divided into potential layers of volumes $V_1, V_2, \dots V_m, \dots$ corresponding to the potentials $-\phi_1, -\phi_2, \dots -\phi_m, \dots$ respectively. Let at any instant $N_{11}, N_{12}, \dots N_{1m}, \dots$ particles of type (1), and $N_{21}, N_{22}, \dots N_{2m}, \dots$ particles of type (2) be in the layers of volumes $V_1, V_2, \dots V_m, \dots$. The rest of discussion is as before.

CALCULATIONS.

The thermodynamic probability, calculated on distributing the particles of the first type first and then those of the second type, is

$$W_{12} = \Pi \frac{\left(\frac{V_m}{b_1}\right)!}{N_{1m}! \left(\frac{V_m}{b_1} - N_{1m}\right)!} \cdot \frac{\left(\frac{V_m - N_{1m}b_{12}}{b_2}\right)!}{N_{2m}! \left(\frac{V_m - N_{1m}b_{12}}{b_2} - N_{2m}\right)!} \cdot \frac{N_1!}{\Pi a_i!} \cdot \frac{N_2!}{\Pi a'_i!}$$

Taking logarithm after approximation by Stirling's formula, and applying the principle of symmetrisation of thermodynamic probability, we obtain

$$\log W = \left[\frac{1}{2} \sum \left\{ \left(\frac{V_m}{b_1}\right) \log \left(\frac{V_m}{b_1}\right) - 2N_{1m} \log N_{1m} - \left(\frac{V_m}{b_1} - N_{1m}\right) \log \left(\frac{V_m}{b_1} - N_{1m}\right) \right\} \right]$$

$$\begin{aligned}
& + \left(\frac{V_m - N_{1m} b_{12}}{b_2} \right) \log \left(\frac{V_m - N_{1m} b_{12}}{b_2} \right) - 2N_{2m} \log N_{2m} \\
& - \left(\frac{V_m - N_{1m} b_{12}}{b_2} - N_{2m} \right) \log \left(\frac{V_m - N_{1m} b_{12}}{b_2} - N_{2m} \right) \\
& + \left(\frac{V_m}{b_2} \right) \log \left(\frac{V_m}{b_2} \right) - \left(\frac{V_m}{b_2} - N_{2m} \right) \log \left(\frac{V_m}{b_2} - N_{2m} \right) \\
& - \left(\frac{V_m - N_{2m} b_{12}}{b_1} \right) \log \left(\frac{V_m - N_{2m} b_{12}}{b_1} \right) \\
& - \left(\frac{V_m - N_{2m} b_{12}}{b_1} - N_{1m} \right) \log \left(\frac{V_m - N_{2m} b_{12}}{b_1} - N_{1m} \right) \} \\
& + N_1 \log N_1 + N_2 \log N_2 - \sum_i a_i \log a_i - \sum_n a'_n \log a'_n \Big]. \quad \dots \quad (31)
\end{aligned}$$

This is to be maximised subject to the following conditions :

$$\left. \begin{aligned}
N_{11} + N_{12} &= N_1 \\
N_{21} + N_{22} &= N_2 \\
\sum_i a_i &= N_1 \\
\sum_n a'_n &= N_2 \\
\sum_m (N_{1m} m_1 + N_{2m} m_2) \phi_m + \sum_i a_i \epsilon_i + \sum_n a'_n \eta_n &= E
\end{aligned} \right\} \quad \dots \quad (32)$$

where $N_1, N_2, E, V_1, V_2 \dots V_m, \dots$ are to remain constant in the variation.

On using Lagrange's undetermined multipliers, as usual we have

$$\left. \begin{aligned}
a_i &= e^{-\lambda_1 - \mu \epsilon_i}, \text{ (for all } i\text{'s)} \\
a'_n &= e^{-\lambda_2 - \mu \eta_n}, \text{ (for all } n\text{'s)}
\end{aligned} \right\} \quad \dots \quad (33)$$

$$\begin{aligned}
\left(\frac{V_m}{N_{1m} b_1} - 1 \right)^{\frac{1}{2}} \left(\frac{V_m - N_{2m} b_{12}}{N_{1m} b_1} - 1 \right)^{\frac{1}{2}} \left(1 - \frac{N_{2m} b_2}{V_m - N_{1m} b_{12}} \right)^{\frac{b_{12}}{2b_2}} &= e^{\nu_1 + \mu m_1 \phi_m} \\
\left(\frac{V_m}{N_{2m} b_2} - 1 \right)^{\frac{1}{2}} \left(\frac{V_m - N_{1m} b_{12}}{N_{2m} b_2} - 1 \right)^{\frac{1}{2}} \left(1 - \frac{N_{1m} b_1}{V_m - N_{2m} b_{12}} \right)^{\frac{b_{12}}{2b_1}} &= e^{\nu_2 + \mu m_2 \phi_m} \\
&\text{(for all } m\text{'s).}
\end{aligned}$$

Now in gases

$$\frac{N_{1m} b_1}{V_m}, \quad \frac{N_{1m} b_{12}}{V_m}, \quad \frac{N_{2m} b_2}{V_m}, \quad \frac{N_{2m} b_{12}}{V_m} \ll 1$$

(for all m 's).

Hence, up to the zeroth approximation, we obtain

$$\frac{V_m}{N_{1m} b_1} = e^{\nu_1 + \mu m_1 \phi_m}, \quad \frac{V_m}{N_{2m} b_2} = e^{\nu_2 + \mu m_2 \phi_m}$$

or

$$N_{1m} = \frac{V_m}{b_1} e^{-\nu_1 - \mu m_1 \phi_m}, \quad N_{2m} = \frac{V_m}{b_2} e^{-\nu_2 - \mu m_2 \phi_m} \quad (34)$$

(for all m 's).

Up to the first approximation, we obtain,

$$\frac{V_m}{N_{1m} b_1} \left(1 - \frac{1}{2} \frac{N_{1m} b_1}{V_m} \right) \left(1 - \frac{1}{2} \frac{N_{2m} b_{12}}{V_m} - \frac{1}{2} \frac{N_{1m} b_1}{V_m} \right) \left(1 - \frac{1}{2} \frac{N_{2m} b_{12}}{V_m} \right) = e^{\nu_1 + \mu m_1 \phi_m}$$

or

$$\frac{V_m}{N_{1m} b_1} \left(1 - \frac{N_{1m} b_1}{V_m} - \frac{N_{2m} b_{12}}{V_m} \right) = e^{\nu_1 + \mu m_1 \phi_m},$$

or

$$\frac{V_m}{N_{1m} b_1} \left(1 - \frac{N_{2m} b_{12}}{V_m} \right) = e^{\nu_1 + \mu m_1 \phi_m} + 1.$$

Similarly

$$\frac{V_m}{N_{2m} b_2} \left(1 - \frac{N_{1m} b_{12}}{V_m} \right) = e^{\nu_2 + \mu m_2 \phi_m} + 1.$$

Or

$$\frac{N_{1m} b_1}{V_m} \left(1 - \frac{N_{2m} b_{12}}{V_m} \right)^{-1} = \frac{1}{e^{\nu_1 + \mu m_1 \phi_m} + 1},$$

and

$$\frac{N_{2m} b_2}{V_m} \left(1 - \frac{N_{1m} b_{12}}{V_m} \right)^{-1} = \frac{1}{e^{\nu_2 + \mu m_2 \phi_m} + 1}.$$

Retaining up to first order, we have,

$$\left. \begin{aligned} N_{1m} &= \frac{\left(\frac{V_m}{b_1} \right)}{e^{\nu_1 + \mu m_1 \phi_m} + 1} \\ N_{2m} &= \frac{\left(\frac{V_m}{b_2} \right)}{e^{\nu_2 + \mu m_2 \phi_m} + 1} \end{aligned} \right\} \dots \dots \dots (35)$$

Now, by Boltzmann hypothesis, we have,

$$\begin{aligned} S = k \left[\frac{1}{2} \sum_m \left\{ N_{1m} \left[\log \left(\frac{V_m}{b_1} - N_{1m} \right) + \log \left(\frac{V_m}{b_1} - N_{1m} - \frac{N_{2m} b_{12}}{b_1} \right) + 2 \log N_{1m} \right] \right. \right. \\ \left. \left. + \left(\frac{V_m}{b_1} \right) \left[\log \left(\frac{V_m}{b_1} \right) - \log \left(\frac{V_m}{b_1} - N_{1m} \right) + \log \left(\frac{V_m - N_{2m} b_{12}}{b_1} \right) \right. \right. \right. \\ \left. \left. - \log \left(\frac{V_m - N_{2m} b_{12}}{b_1} - N_{1m} \right) \right] + \frac{N_{1m} b_{12}}{b_2} \left[\log \left(\frac{V_m - N_{1m} b_{12}}{b_2} \right) \right. \right. \right. \\ \left. \left. + \log \left(\frac{V_m - N_{1m} b_{12}}{b_2} - N_{2m} \right) \right] + N_{2m} \left[\log \left(\frac{V_m}{b_2} - N_{2m} - \frac{N_{1m} b_{12}}{b_2} \right) \right. \right. \right. \end{aligned}$$

$$\begin{aligned}
& -2 \log N_{2m} + \log \left(\frac{V_m}{b_2} - N_{2m} \right) \Big] \\
& + \left(\frac{V_m}{b_2} \right) \left[\log \left(\frac{V_m}{b_2} \right) - \log \left(\frac{V_m}{b_2} - N_{2m} \right) \right. \\
& + \log \left(\frac{V_m - N_{1m} b_{12}}{b_2} \right) - \log \left(\frac{V_m - N_{1m} b_{12}}{b_2} - N_{2m} \right) \Big] \\
& + N_{2m} \frac{b_{12}}{b_1} \left[\log \left(\frac{V_m - N_{2m} b_{12}}{b_1} \right) - \log \left(\frac{V_m - N_{2m} b_{12}}{b_1} - N_{1m} \right) \right] \Big\} \\
& + N_1 \log N_1 + N_2 \log N_2 - \sum_i a_i \log a_i - \sum_n a'_n \log a'_n \Big]
\end{aligned}$$

Substituting the values of a_i , a'_n , N_{1m} , N_{2m} from (32) and (34), we have

$$\begin{aligned}
S = k [& N_1(\lambda_1 + \nu_1) + N_2(\lambda_2 + \nu_2) + \mu E + N_1 + N_2 \\
& - \sum_m \frac{N_{1m} N_{2m} b_{12}}{V_m} - \frac{1}{2} \sum_m \frac{N_{1m}^2 b_1}{V_m} - \frac{1}{2} \sum_m \frac{N_{2m}^2 b_2}{V_m} \\
& + N_1 \log N_1 + N_2 \log N_2] \quad \dots \quad \dots \quad \dots \quad \dots \quad (36)
\end{aligned}$$

Now, from well-known thermodynamic relation

$$\frac{1}{T} = \left(\frac{\partial S}{\partial E} \right)_V$$

we obtain

$$\begin{aligned}
\frac{1}{T} = \mu k \text{ or } \mu = \frac{1}{kT}. \\
\therefore \psi = k \left[N_1(\lambda_1 + \nu_1) + N_2(\lambda_2 + \nu_2) + (N_1 + N_2) \right. \\
- \frac{1}{2} \sum_m \frac{N_{1m}^2 b_1}{V_m} - \frac{1}{2} \sum_m \frac{N_{2m}^2 b_2}{V_m} - \frac{1}{2} \sum_m \frac{N_{1m} N_{2m} b_{12}}{V_m} \\
\left. + N_1 \log N_1 + N_2 \log N_2 \right]. \quad \dots \quad \dots \quad \dots \quad \dots \quad (37)
\end{aligned}$$

From equation (31), we have, as usual,

$$\left. \begin{aligned}
\lambda_1 &= \log \left\{ \frac{1}{N_1} \cdot \frac{b_1}{h^3} (2\pi m_1 kT)^{3/2} \right\} \\
\lambda_2 &= \log \left\{ \frac{1}{N_2} \cdot \frac{b_2}{h^3} (2\pi m_2 kT)^{3/2} \right\} \\
\nu_1 &= \log \left\{ \frac{1}{N_1 b_1} \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\} \\
\nu_2 &= \log \left\{ \frac{1}{N_2 b_2} \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}
\end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (38)$$

Also

$$\begin{aligned}
 \sum_m \frac{N_{1m}^2 b_1}{V_m} &= \frac{1}{b_1} \int_V e^{-2v_1 - \frac{2m_1 \phi_m}{kT}} dV = N_1^2 b_1 \frac{\int_V e^{-\frac{2m_1 \phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\}^2} \\
 \sum_m \frac{N_{2m}^2 b_2}{V_m} &= N_2^2 b_2 \frac{\int_V e^{-\frac{2m_2 \phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}^2} \\
 \sum_m \frac{N_{1m} N_{2m} b_{12}}{V_m} &= \frac{b_{12}}{b_1 b_2} \int_V e^{-(v_1 + v_2) - \frac{(m_1 + m_2) \phi}{kT}} dV \\
 &= N_1 N_2 b_{12} \frac{\int_V e^{-\frac{(m_1 + m_2) \phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\} \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}} \\
 \therefore \psi &= k \left[N_1 \log \left\{ \frac{b_1 (2\pi m_1 kT)^{3/2}}{h^3 N_1} \right\} + N_2 \log \left\{ \frac{b_2 (2\pi m_2 kT)^{3/2}}{h^3 N_2} \right\} \right. \\
 &\quad + N_1 \log \left(\frac{1}{N_1 b_1} \int_V e^{-\frac{m_1 \phi}{kT}} dV \right) + N_2 \log \left(\frac{1}{N_2 b_2} \int_V e^{-\frac{m_2 \phi}{kT}} dV \right) \\
 &\quad + (N_1 + N_2) + N_1 \log N_1 + N_2 \log N_2 \\
 &\quad - \frac{N_1 b_1}{2} \frac{\int_V e^{-\frac{2m_1 \phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\}^2} - \frac{N_2 b_2}{2} \frac{\int_V e^{-\frac{2m_2 \phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}^2} \\
 &\quad \left. - N_1 N_2 b_{12} \frac{\int_V e^{-\frac{(m_1 + m_2) \phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\} \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}} \right] \dots \dots (39)
 \end{aligned}$$

From the well-known thermodynamic relation

$$p = T \left(\frac{\partial \psi}{\partial V} \right)_T$$

we have

$$\begin{aligned}
 p = kT & \left[N_1 \frac{e^{-\frac{m_1 \phi_B}{kT}}}{\int_V e^{-\frac{m_1 \phi}{kT}} dV} + N_2 \frac{e^{-\frac{m_2 \phi_B}{kT}}}{\int_V e^{-\frac{m_2 \phi}{kT}} dV} \right. \\
 & - \frac{N_1^2 b_1}{2} \cdot \frac{e^{-\frac{2m_1 \phi_B}{kT}} \left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\}^2 - 2 \left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\} \left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\} e^{-\frac{m_1 \phi_B}{kT}}}{\left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\}^4} \\
 & - \frac{N_2^2 b_2}{2} \cdot \frac{e^{-\frac{2m_2 \phi_B}{kT}} \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}^2 - 2 \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\} \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\} e^{-\frac{m_2 \phi_B}{kT}}}{\left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}^4} \\
 & \left. - N_1 N_2 b_{12} \frac{e^{-\frac{(m_1+m_2)\phi_B}{kT}} \left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\} \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\} - A \int_V e^{-\frac{(m_1+m_2)\phi}{kT}} dV}{\left\{ \int_V e^{-\frac{m_1 \phi}{kT}} dV \right\}^2 \left\{ \int_V e^{-\frac{m_2 \phi}{kT}} dV \right\}^2} \right]
 \end{aligned}$$

$$\text{where } A = \left\{ \left(\int_V e^{-\frac{m_1 \phi}{kT}} dV \right) e^{-\frac{m_2 \phi_B}{kT}} + \left(\int_V e^{-\frac{m_2 \phi}{kT}} dV \right) e^{-\frac{m_1 \phi_B}{kT}} \right\}$$

$$\begin{aligned}
 = kT & \left[N_1 \frac{e^{-\frac{m_1 \phi_B}{kT}}}{V+a_1} + N_2 \frac{e^{-\frac{m_2 \phi_B}{kT}}}{V+a_2} \right. \\
 & + N_1 \frac{e^{-\frac{m_1 \phi_B}{kT}}}{V+a_1} \cdot \frac{N_1 b_1}{2(V+a_1)} \cdot \left\{ \frac{2(V+a_1')}{V+a_1} - e^{-\frac{m_1 \phi_B}{kT}} \right\} \\
 & + N_2 \frac{e^{-\frac{m_2 \phi_B}{kT}}}{V+a_2} \cdot \frac{N_2 b_2}{2(V+a_2)} \cdot \left\{ \frac{2(V+a_2')}{V+a_2} - e^{-\frac{m_2 \phi_B}{kT}} \right\} \\
 & + N_1 \frac{e^{-\frac{m_1 \phi_B}{kT}}}{V+a_1} \cdot \frac{N_2 b_{12}}{2(V+a_2)} \cdot \left\{ \frac{2(V+a_{12})}{V+a_1} - e^{-\frac{m_2 \phi_B}{kT}} \right\} \\
 & \left. + N_2 \frac{e^{-\frac{m_2 \phi_B}{kT}}}{V+a_2} \cdot \frac{N_1 b_{12}}{2(V+a_1)} \cdot \left\{ \frac{2(V+a_{12})}{V+a_2} - e^{-\frac{m_1 \phi_B}{kT}} \right\} \right]
 \end{aligned}$$

where ϕ_B is the potential at the boundary, and

$$V + a_1 = \int_V e^{-\frac{m_1 \phi}{kT}} dV,$$

$$V + a_1' = \int_V e^{-\frac{2m_1 \phi}{kT}} dV,$$

$$V + a_2 = \int_V e^{-\frac{m_2 \phi}{kT}} dV,$$

$$V + a_2' = \int_V e^{-\frac{2m_2 \phi}{kT}} dV,$$

$$V + a_{12} = \int_V e^{-\frac{(m_1 + m_2) \phi}{kT}} dV.$$

$$p = NkT \left[c_1 \frac{e^{-\frac{m_1 \phi_B}{kT}}}{V + a_1} \left\{ 1 + c_1 \frac{\beta_1}{V + a_1} \left(2 \frac{V + a_1'}{V + a_1} - e^{-\frac{m_1 \phi_B}{kT}} \right) \right. \right. \\ \left. \left. + c_2 \frac{\beta_{12}}{V + a_2} \left(2 \frac{V + a_{12}}{V + a_1} - e^{-\frac{m_2 \phi_B}{kT}} \right) \right\} \right. \\ \left. + c_2 \frac{e^{-\frac{m_2 \phi_B}{kT}}}{V + a_2} \left\{ 1 + c_2 \frac{\beta_2}{V + a_2} \left(2 \frac{V + a_2'}{V + a_2} - e^{-\frac{m_2 \phi_B}{kT}} \right) \right. \right. \\ \left. \left. + c_1 \frac{\beta_{12}}{V + a_1} \left(2 \frac{V + a_{12}}{V + a_2} - e^{-\frac{m_1 \phi_B}{kT}} \right) \right\} \right]$$

where $\beta_1, \beta_2, \beta_{12}$ have the same significances as in equation (15).

Or

$$p = NkT \left[c_1 \frac{e^{-\frac{m_1 \phi_B}{kT}}}{V + a_1 - c_1 \beta_1' - c_2 \beta_{12}'} + c_2 \frac{e^{-\frac{m_2 \phi_B}{kT}}}{V + a_2 - c_2 \beta_2' - c_1 \beta_{21}'} \right]$$

where

$$\beta_1' = \beta_1 \left(2 \frac{V + a_1'}{V + a_1} - e^{-\frac{m_1 \phi_B}{kT}} \right)$$

$$\beta_{12}' = \beta_{12} \left(2 \frac{V + a_{12}}{V + a_2} - e^{-\frac{m_2 \phi_B}{kT}} \right)$$

$$\beta_2' = \beta_2 \left(2 \frac{V + a_2'}{V + a_2} - e^{-\frac{m_2 \phi_B}{kT}} \right)$$

$$\beta_{21}' = \beta_{12} \left(2 \frac{V + a_{12}}{V + a_2} - e^{-\frac{m_1 \phi_B}{kT}} \right).$$

Now, as in a previous paper (Dutta, III, 1949), we take ϕ_B as weak compared to kT and $\phi_B \propto \frac{N}{V}$, and we write

$$\frac{m_1 \phi_B}{kT} = \frac{\alpha_1}{NkTV},$$

$$\frac{m_2 \phi_B}{kT} = \frac{\alpha_2}{NkTV},$$

$$\gamma_1 = c_1 \beta_1' + c_2 \beta_{12}' - \alpha_1,$$

$$\gamma_2 = c_2 \beta_2' + c_1 \beta_{21}' - \alpha_2.$$

Then

$$\alpha_1, \alpha_2 \propto N^2$$

and γ_1, γ_2 can be shown to be proportional to N .

Thus, ultimately, we can write

$$p = NkT \left\{ c_1 \frac{e^{-\frac{\alpha_1}{NkTV}}}{V - \gamma_1} + c_2 \frac{e^{-\frac{\alpha_2}{NkTV}}}{V - \gamma_2} \right\} \quad \dots \quad (40)$$

This may be regarded as the Dieterici Equation of States for mixture of gases.

CONCLUSION.

Here, it is found that the present method with a principle of symmetrisation of thermodynamic probability is sufficiently powerful for considering mixture of real gases under Van der Waals' field of force. The method is also conveniently applied to real gases under any field leading to a form of Dieterici's Equation of state for mixture of gases, which may be helpful for future experiments with mixture of gases.

SUMMARY.

In this paper, a new statistical theory of imperfect gases, developed in three previous papers (Dutta, 1947, 1948 and 1951), has been naturally extended with suitable modifications to a mixture of imperfect gases. For simplicity, the mixture of gases has been taken to have only two components. Two quantities b_1 and b_2 are supposed to denote respectively two rigid volumes of exclusion of molecules of the two types for molecules of the same type, and in considering distribution of molecules of type (1), the available configurational space has been divided into cells of volume b_1 , and similarly, for molecules of type (2), the same has been divided into cells of volume b_2 . Another quantity b_{12} has been introduced to denote the volume of exclusion of molecules of one type for molecules of other type. The effect of the finite size of molecules has been considered by help of a principle of exclusion, analogous to that of Fermi. For the effect of cohesion, which has been considered in the second part of this paper, the configuration space has been divided into two layers, one interior, of volume v_1 , and other, a surface layer of volume v_2 . The distribution in configurational space has been calculated after Fermi, and that in momenta space after Planck and Lorentz. In this way, the equation of state, yielding Van der Waals' Equation for mixture of gases, has been obtained. Also on extending the method to the field of forces as described in the paper (Dutta, III, 1950), the form of Dieterici's Equation for mixture of gases has been worked out.

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RADIAL OSCILLATIONS OF A GASEOUS STAR OF POLYTROPIC INDEX I.

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SUMMARY.

The periods of the fundamental, first, and second modes of pulsations have been found out for a star of polytropic index $n = 1$.

The radial oscillations of a gaseous star of the polytrope $n = 3$ (standard model) were first investigated by Eddington (1926). His method consisted in numerical integration of the pulsation equation by finite differences, to find the period of the adiabatic radial oscillation of the standard model. Recently Schwarzschild (1941) with much more greater accuracy has found out the periods of the first four spherically symmetrical overtone pulsations for the standard model. Miller (1929) extended the calculations to the models of polytrope $n = 2$, and $n = 4$, his work was based on the single value $\alpha = 0.2$, which corresponds to the ratio of specific heats, $\gamma = 10/7$. In the present note a similar investigation is made for the polytrope $n = 1$ to find the periods of the fundamental, first, and second modes for $\alpha = 0.6$, which corresponds to $\gamma = 5/3$, and also the periods of the fundamental mode for $\alpha = 0.4$ and $\alpha = 0.2$, which corresponds to $\gamma = \frac{20}{13}$ and $\gamma = \frac{10}{7}$ respectively.

The differential equation for small adiabatic radial oscillation, as given by Eddington, is

$$\frac{d^2 f}{dz^2} + \left(\frac{4-\mu}{z} \right) \frac{df}{dz} + \left(\frac{\omega^2}{u} - \frac{\alpha\mu}{z^2} \right) f = 0 \quad \dots \quad (1)$$

where f is the amplitude of the displacement $\frac{d\xi}{\xi}$, z is proportional to ξ , mean distance from the centre, $\alpha = 3 - \frac{4}{\gamma}$, γ being the ratio of specific heats, u is the Emden function of polytropic index $n = 1$, $\mu = \frac{g_0 \rho_0 z}{P_0}$, g_0 , ρ_0 , P_0 , being respectively the mean values of gravity, density, and pressure at a distance z from the centre, $\omega^2 = v^2 (2\pi G \rho_c \gamma)^{-1}$, where the period $\Pi = \frac{2\pi}{v}$, G , the constant of Gravitation and ρ_c the mean density at the centre. Equation (1) has a solution non-singular both at $z = 0$, and z at the surface of the star.

For the polytrope $n = 1$, the well-known Emden equation is

$$\frac{d^2 u}{dz^2} + \frac{2}{z} \frac{du}{dz} + u = 0$$

which gives $u = \frac{\sin z}{z}$ as a solution. From Emden's theory we have

$$\mu = -(n+1) \frac{z}{u} \frac{du}{dz}, \text{ for } n = 1, \mu = -2 \frac{z}{u} \frac{du}{dz}, \text{ i.e. } \mu = -2(z \cot z - 1).$$

With this value of μ the pulsation equation (1) takes the form

$$\frac{d^2f}{dz^2} + \frac{2(1+z \cot z)}{z} \frac{df}{dz} + \left\{ \frac{\omega^2 z}{\sin z} + \frac{2\alpha(z \cot z - 1)}{z^2} \right\} f = 0 \dots \dots (2)$$

This equation has been solved numerically. All the calculations have been done with the help of Mathematical Tables I (1946) of the British Association for the Advancement of Science, and the calculating machine. Table I gives the resulting characteristic values of ω^2 . Table II gives the amplitudes f of the displacements

TABLE I.
Characteristic values of ω^2 .

Mode.	$\alpha = 0.6$.	$\alpha = 0.4$.	$\alpha = 0.2$.
0	0.231	0.155	0.078
1	1.517		
2	3.580		

TABLE II.
Amplitudes of the Displacements, f .

z	Fundamental. $\alpha = 0.6$.	First Overtone. $\alpha = 0.6$.	Second Overtone. $\alpha = 0.6$.
0.0	+1.000000	+1.000000	+1.000000
0.1	1.000169	0.998882	0.996820
0.2	1.000677	0.995518	0.987281
0.3	1.001525	0.989874	0.971386
0.4	1.002716	0.981890	0.949136
0.5	1.004251	0.971495	0.920555
0.6	1.006143	0.958596	0.885671
0.7	1.008389	0.943052	0.844515
0.8	1.011009	0.924713	0.797168
0.9	1.014006	0.903389	0.743728
1.0	1.017390	0.878859	0.684350
1.1	1.021175	0.850865	0.619257
1.2	1.025374	0.819105	0.548757
1.3	1.030004	0.783221	0.473277
1.4	1.035102	0.742868	0.393396
1.5	1.040853	0.697654	0.309941
1.6	1.047084	0.646920	0.223844
1.7	1.053810	0.590042	0.136419
1.8	1.061066	0.526318	+0.049379
1.9	1.068886	0.454939	-0.035065
2.0	1.077309	0.374974	-0.114079
2.1	1.086374	0.285357	-0.184050
2.2	1.096138	0.184876	-0.240444
2.3	1.106766	+0.072271	-0.277903
2.4	1.118204	-0.054152	-0.288854
2.5	1.130496	-0.196154	-0.264401
2.6	1.143708	-0.355598	-0.193931
2.7	1.157893	-0.534282	-0.065351
2.8	1.173099	-0.733397	+0.133422
2.9	1.189288	-0.951614	+0.408698
3.0	1.206063	-1.175893	+0.734701
3.1	+1.218532	-1.251806	+0.780444

as functions of mean distance from the centre for the fundamental, first and second mode (for $\alpha = 0.6$). Figure 1 shows the amplitudes f of the displacements as functions of mean distance z from the centre for the fundamental, first, and second mode.

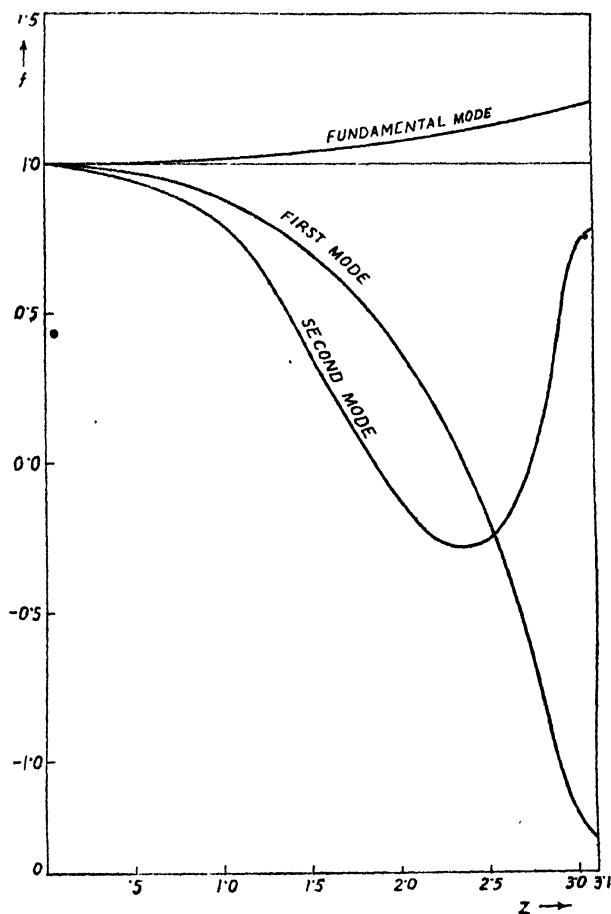


FIG. 1.—The amplitudes f of the displacements in the fundamental and the first two modes for $\alpha = 0.6$, as functions of the mean distance z from the centre.

The characteristic values of ω^2 were determined in the following way. A trial value of ω^2 was chosen for $\alpha = 0.6$. For the neighbourhood of $z = 0$ and z at the surface of the star, which in our case is $z = \pi$, equation (2) was solved by power series; the series developed at $z = 0$ (neglecting eighth and higher powers) was used to compute f at $z = 0, 0.1, 0.2, 0.3$ respectively, and with these starting values the integrations of the equation (2) have been performed numerically starting with the arbitrary amplitude $f = 1$ at the centre and the solution is continued towards the surface until it becomes evident how it is going to behave at the surface itself. The condition for the Node to fall at the surface of the star being

$$3f + z \frac{df}{dz} = 0.$$

As the adiabatic approximation breaks down near the boundary we have not strictly followed this condition. After a few successive trials the characteristic value of

ω^2 for the fundamental mode for $\alpha = 0.6$ was located between 0.22 and 0.24. This approximation for ω^2 was utilised to obtain the characteristic value of ω^2 correct up to third place in the subsequent integrations and fair accuracy has been obtained with the help of interpolation. We have followed Adam's method of integration as sketched by Von Zeipel (1924) in one of his papers in doing all the integrations. For the correct value of ω^2 it has been observed that the displacement functions show a steady increase in going from the centre right up to the surface of the star for the fundamental mode. Adjacent solutions have been found to show signs of running off to positive or negative infinity. We have found that a lower value of ω^2 would give abrupt increase in the displacement function at the surface of the star, whereas a higher value of ω^2 would give abrupt decrease in the displacement function at the surface of the star. This idea has greatly facilitated in arriving at the correct characteristic values of ω^2 for the fundamental mode. Similar processes with some modification have been followed for finding out the characteristic values of ω^2 for the first and second modes for $\alpha = 0.6$.

We have found the periods of pulsations for the first and second modes as we shall study the Anharmonic pulsations for the polytrope $n = 1$ in the next paper, which is under preparation.

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A NOTE ON THE THEORY OF TWO-PHASE CONFIGURATION.

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(Communicated by Dr. D. S. Kothari, F.N.I.)

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SUMMARY.

Bondi's semi-graphical method of integration of equations of stellar structure is applied to Milne's two phase model of white-dwarf stars, and the results compared with those obtained earlier by Kothari.

Recently Bondi and Bondi (1949) have given a new method of integration of the equations of stellar structure. This method differs from others in that it is sufficiently simple and that the mathematical consequences of any particular physical assumptions for any particular stellar structure can be seen at a glance qualitatively and worked out with comparative ease quantitatively.

The method makes use of non-dimensional homology-invariant physical variables which depend on the equations of conservation of mass and hydrostatic support and not on the equations of energy-transport which are different for different models.

In the present note this method is applied to Milne's two phase model of white-dwarf stars and the results obtained agree substantially with those obtained earlier by Kothari. Marshak (1940) has also evaluated the radii of white dwarf stars, but he has not taken into consideration the two-phase configuration.

The method of Bondi and Bondi can be summarised as follows:—

We introduce the non-dimensional homology-invariant variables

$$S = 4\pi \frac{Pr^4}{GM^2}; \quad Q = \frac{Pr}{GM\rho}; \quad N = 1 - \frac{d \log \rho}{d \log P} \quad \dots \quad (1)$$

and take S as independent variable and $Q = Q(S)$; $N = N(S)$. Here all the symbols have their usual significance (Bondi and Bondi, 1949). The two principal star equations of hydrostatic support

$$\frac{dP}{dr} = - \frac{GM\rho}{r^2} \quad \dots \quad (2)$$

and conservation of mass

$$\frac{dM}{dr} = 4\pi r^2 \rho \quad \dots \quad (3)$$

can, then, be expressed in the form

$$\frac{S}{Q} \frac{dQ}{dS} = \frac{S+N-Q}{1+2S-4Q} \quad \dots \quad (4)$$

which is valid throughout the star. The expressions for r and M are obtained as

$$\left. \begin{aligned} \log \frac{r}{r_s} &= - \int_0^S \frac{Q dS}{S(1+2S-4Q)} = - \int_0^Q \frac{dQ}{S+N-Q} \\ \log \frac{M}{M_s} &= - \int_0^S \frac{dS}{1+2S-4Q} \end{aligned} \right\} \quad \dots \quad (5)$$

Now a particular solution of eqn. (4) for $N = \text{constant}$ when expressed in the usual variables, is the Emden-function for that value of N . The surface of a star corresponds to $S = Q = 0$, while the centre corresponds to S and Q infinite. The boundary conditions are that $Q \sim \frac{S}{3}$ as $S \rightarrow \infty$ and $N \rightarrow N^c$ at the centre, and $N \rightarrow N_s$, $Q \sim S^{N_s}$ at the surface.

To find a solution $Q = Q(S)$, $N = N(S)$ at a particular point of the star we need a subsidiary condition which is supplied by the energy transport dependence on temperature gradient and differs from region to region. The system of equations are then integrable by a semi-graphical method as follows.

First we need an initial point from which the integration of a solution may be continued. To get it we consider the case of the region running right up to the surface of a star. It is then possible to find a series expansion for N and Q in terms of S in the neighbourhood of the point $(0, 0, N_s)$, which is of the form $Q = AS^{N_s}$, A being some parameter. The first points of Q and N are obtained by the first few term of the expansion in the immediate neighbourhood of the surface. Having thus obtained a starting point, say, S', Q', N' we can find the next point S'', Q'', N'' where $S'' - S'$ is small and positive.

For that we take the set of graphs of solutions of equation (4) for the nearest N value below N' , select this point (S', Q') on it and by interpolation between adjacent curves find the point Q_a'' for $S = S''$. Repeating this procedure on the graph for the nearest N value above N' , we get Q_b'' . The first approximation to Q'' corresponding to S'' is found by linear interpolation between these two values of N .

The correct value of N'' is found by calculating dN from the subsidiary equation for S', Q', N' and $dS = S'' - S'$. This leads to a first approximate to the value of N'' at S'' , and the process is repeated using this value of N and the value of S'', Q'' and $dS = S'' - S'$. The mean of these two extreme values of dN thus found is taken to be the correct one.

This graphical procedure is continued till the solution cuts the corresponding Emden solution of the core. In the present problem graphs drawn by the Bondis were utilised and more graphs for different values of A and N were drawn and the method of step-by-step integration also used.

Considering Milne's two phase model of the white-dwarf star we have a degenerate convective core surrounded by a perfect gas envelope. Assuming the ratio of specific heats as $5/3$ in the core, and constant opacity due to electron scattering only in the radiative envelope, the equation of state valid throughout the star is

$$\frac{S}{Q} \frac{dQ}{dS} = \frac{S + N - Q}{1 + 2S - 4Q}.$$

In the radiative envelope we have the subsidiary condition

$$\frac{S}{N} \frac{dN}{dS} = \frac{1 + S - 4N}{1 + 2S - 4Q}.$$

Thus in the core $N = 0.4$ and at the surface $N = \frac{1}{4}$, $Q = AS^{1/4}$. The solution for the core is the well-known Emden's function with index 1.5.

The series expansion of the solution in the neighbourhood of the surface are

$$Q = AS^{1/4} + \frac{5}{8} AS^{5/4} + \frac{98}{45} A^2 S^{9/4} + \dots$$

$$N = \frac{1}{4} + \frac{1}{8} S + \frac{2}{9} AS^{5/4} + \frac{4}{9} A^2 S^{9/4} + \dots$$

Curves are plotted for different values of A and the cut with Emden's solution for $N^* = 0.4$ obtained. For these points, $\frac{r_i}{r_s}$ and $\frac{M_i}{M_s}$ are obtained by the quadrature of (5).

Next we consider the case in which Kramer's absorption neglecting the guillotine factor is the main source of opacity in the radiative envelope, the other conditions being as before. The subsidiary condition now is

$$\frac{S}{N} \frac{dN}{dS} = \frac{S+2-8.5N}{1+2S-4Q}.$$

The series expansion near the surface are

$$Q = \theta - \frac{1}{4}\theta^2 - \frac{7}{16}\theta^3 - \frac{65}{64}\theta^4 - \frac{667}{256}\theta^5 + \frac{31}{55}S\theta + \dots$$

$$N = \frac{4}{17} + \frac{4}{51}S + \frac{16}{165}S\theta + \frac{1124}{9735}S\theta^2 + \dots$$

where $\theta = AS^{4/17}$.

Curves for different A 's are plotted and the values of r_i/r_s and M_i/M_s etc. obtained as before.

The ratio r_i/r_s for the constant electron opacity and for the Kramer's law for various values of A are given in columns two and three of the following table. For the sake of comparison, the corresponding results of Kothari for constant electron opacity are inserted in column four. The ratio M_i/M_s for the two cases are given in columns five and six.

A	r_i/r_s			M_i/M_s	
	Constant opacity.	Kramer's Law.	Kothari's constant opacity.	Constant opacity.	Kramer's Law.
0.0224	0.998	0.996	0.998	1.00	1.00
0.0787	0.944	0.927	0.942	0.999	0.998
0.1245	0.816	0.790	0.83	0.977	0.975
0.176	0.619	0.606	0.61	0.879	0.885
0.249	0	0	0	0	0

It is to be noted that the parameter A is connected with ω_0 the initial slope with which the solution start from the surface in case of Kothari's investigation by the relation

$$A = (8\omega_0)^{-\frac{1}{2}} = (8C^{-\frac{1}{2}})^{-\frac{1}{2}}$$

where

$$C = \frac{16(R/m_H)^4}{\pi^{\frac{1}{2}}aG^3M^2\mu^4} \frac{1-\beta_1}{\beta_1^4}.$$

Here all the symbols have their usual significance (Kothari, 1932).

A glance at the table shows that the values of r_i/r_s calculated by Kothari and those calculated here for constant opacity do not differ very much. As A approaches its value 0.249 corresponding to Emden's solution the method for accurate determination of r_i/r_s becomes laborious.

In conclusion we would like to thank Dr. D. S. Kothari for suggesting the problem and Dr. P. L. Bhatnagar for helpful discussions.

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FURTHER STUDIES REGARDING HORA'S SATPURA HYPOTHESIS.

1. THE RÔLE OF THE EASTERN GHATS IN THE DISTRIBUTION OF THE MALAYAN FAUNA AND FLORA TO PENINSULAR INDIA.

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INTRODUCTION.

In the Symposium on the Satpura Hypothesis published by the National Institute of Sciences of India, in discussing some peculiarities of the avifaunal distribution in Peninsular India, Abdulali suggested 'an alternate possibility of the species having reached South-West India through the Eastern Ghats'. He supported this view by the following statements:—

'Our knowledge of the natural history of the Eastern Ghats is much scantier than that of the West. Few people have done very serious collecting and most of the information that is available from that area is in the form of fragmentary notes. On south of the Rajmahal Hills, the Chota Nagpur area is common to both the Satpura route and one southward through the Vizagapatam Ghats. The data from the Vizagapatam Ghats forms an important part of the List No. II and also supports the opinion that the migration moved southwards in this direction. Mahendragiri in the Northern Circars and the Nallamalai and other hills which go to form the Eastern Ghats have not been carefully worked and it is quite possible that they may have been an important highway to Malabar and Ceylon. It is, of course, possible that this area merely forms a *cul-de-sac* southwards and is of no further significance.

The Eastern Ghats also appear to form an important route for some migrant forms which are known from the Malabar area but have not been recorded in the strip of Western Ghats further north.' (Abdulali, 1949, p. 390.)

Mooney (1942) in discussing the origin of the flora of the Bailadila Range, Bastar State, observed:

'Its strength would seem to derive from the easy line of migration provided by the Rajmahal Hills, the highlands of Chota-Nagpur, the mountains of Orissa and the hills of the Eastern Ghats, which terminate only some 100 miles or so east of Bailadila, and the hills intervening between the Eastern Ghats and our area.' He further observed that 'it is not a far cry from the Rajmahal Hills to the Bengal Duars and the hills of Sikkim and Assam. This provides a route by which plants could have migrated from Burma.'

Hora (1949, p. 362) in discussing climates as affecting the Satpura Hypothesis referred to the Chota-Nagpur, Orissa, Jeypore, Eastern Ghats and Mysore Plateau Track and stated:

It will be seen 'that along this track the rainfall is less in the middle than at the two ends, and the conditions of temperature, humidity and duration of rainy season are more uniform as at present than along the Satpura track.'

In suggesting future lines of work on the Satpura Hypothesis, Dr. Ernst Mayr suggested to Dr. Hora that 'More attention should be paid to the eastern prong of colonisation, going through Bastar and the Eastern Ghats.'

Dr. Hora (1949, p. 363) has already stated that 'Though Evidence of fish migration along this route is lacking, there is some evidence among birds and terrestrial organisms.' As regards the probable origin of the Bailadila flora, he gave it a Pleistocene age and stated:

'. . . it seems that dispersal must have taken place during the "Pluvial periods," when, as a result of glaciation in the northern hemisphere, the climates all over India were damper and more humid. Such favourable conditions for the dispersal of plants and terrestrial animals must have been more marked along hill ranges and must have lasted longer at higher altitudes, for they persist even today on the tops of isolated hills in Central and Southern India, and in humid situations along the Western and Eastern Ghats. As there is almost a continuous hill range from the Western Ghats to the Assam hills in the Vindhya Satpura Trend of mountains, it must have formed the most favourable route for the dispersal of both plants and terrestrial animals during these periods, and then along the almost continuous Western Ghats to Ceylon. Except at higher altitudes and in other suitable places, the moisture-loving flora and fauna must have died out during the "Arid periods" alternating with the "Pluvial periods". As there were three Glacial periods during the Pleistocene, the present-day flora of the Bailadila range may be taken as the accumulative result of three distinct invasions and this would explain some of the anomalies in the distribution of plants and animals.'

In another place in the Symposium, Hora (1949a, p. 350) has referred to the climate as the chief factor in the dispersal of terrestrial forms and stated:

'It may be noted that dampness, rather than any other climatic factor, has been responsible for the dispersal of terrestrial "Malayan" forms to Peninsular India. The last and third phase of the last Glaciation occurred about 23,000 years ago. It was probably connected with the second phase, which started 70,000 years ago, by an interstadial, which in the north was pronouncedly cool. It is quite possible, therefore, that for a period of about 50,000 years prior to 20,000 years ago the climate was more humid in the peninsula and favoured the dispersal of the terrestrial forms referred to above. It is not improbable, therefore, that whereas the aquatic forms began to migrate to South India a few million years ago, the terrestrial forms mostly migrated during the above-noted 50,000 years of damp climates in India.'

Whereas new colonisations by terrestrial organisms would seem to depend on climatic factors, in the case of aquatic organism barriers are formed by drainage systems. Though the Eastern Ghats undoubtedly contain many elements of the Malayan flora and fauna belonging to the terrestrial groups, the same may or may not be the case with regard to aquatic forms. At the suggestion of Dr. S. L. Hora, therefore, a detailed survey of the fish-fauna of the Eastern Ghats was undertaken in September-October, 1950, and a large collection of fish was made and worked out. All earlier accounts of fishes from the Orissa hills and the Eastern Ghats have been collated and their present range of distribution noted. On the basis of this material and what has been stated above regarding the distribution of terrestrial forms, the role of the Eastern Ghats in the distribution of the Malayan element in the fauna and flora to Peninsular India is discussed against the background of comparatively recent palaeogeographical and climatic changes in India. The conclusion seems irresistible that the different factors that operate for the dispersal of aquatic and terrestrial forms respectively have given us different patterns of distribution so far as the Eastern Ghats are concerned but this has not detracted in any way the

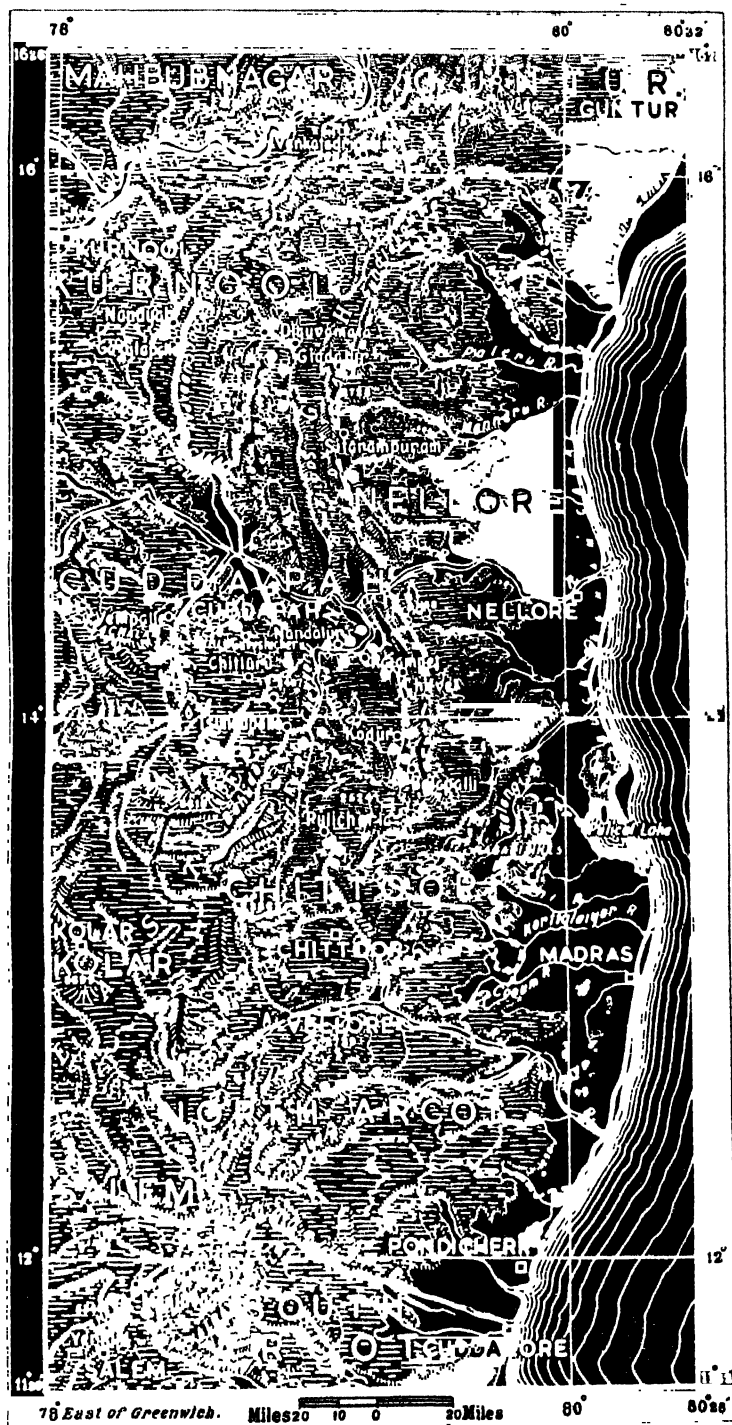
soundness of the Satpura Hypothesis as propounded by Hora and supported by a great deal of evidence by the various writers of the Symposium.

DESCRIPTION OF THE AREAS SURVEYED BY THE AUTHOR.

The area covered by the writer (18° – 20° N. and 82° and 84° E.) is the Eastern Ghats region which is bounded on the east by the coastal districts of Ganjam (Orissa), Vizagapatam and East Godavari (Madras) and on the west by the plateau states of Orissa (Patna State) and C.P. (Bastar). This portion of the Eastern Ghats which is usually known as the Orissa hills is an elevated penepain. On the basis



TEXT-FIG. 1. Map of the Orissa hills showing localities in which the fishes were collected.



TEXT-FIG. 2. Map of the Eastern Ghats showing the localities in which the fishes were collected.
 (From earlier accounts.)

of altitude, drainage pattern and the degree of topographic dissection, the region can be divided into three zones: (1) above 3,000 feet (the largest and the highest—110 miles long with an average width of 40 miles (Francis, 1907, p. 5) extending from the Mahanadi basin on the north to the Godavari in the south), (2) west of and parallel to this, is the undulating tableland (plateau-like) of the Jeypore and Naurangpur taluks of the Koraput district (Orissa) with an average elevation of 2,000 feet and (3) the highly dissected hilly region with an average elevation between 500 and 1,000 feet. The strike of the rocks in the main line is N.E.-S.W. and this trend is also shared by the rocks of the plateau.

The whole of this area is drained by two sets of rivers, namely those which flow eastwards through the coastal plain to the Bay of Bengal and those which drain the ghats westwards into the basin of the Godavari (Francis, *loc. cit.*, pp. 7, 8, 10). The major rivers of the 1st group are the Nagavali and the Vamsadhara whereas the Kolab, the Indravati and the Matchkund form the second set. There are also a large number of perennial streams joining one or the other bigger tributaries of the above rivers in the area surveyed.

A collection of over 3,000 specimens from these streams were procured by netting or damming small streamlets in their rocky beds at various altitudes. The different localities from where collections were made by the writer or already referred to in literature are plotted in the accompanying maps.

The rainfall in this area as a whole is on the average about 60". The heaviest rainfall is in the strip beyond the '3,000 ft. plateau', i.e., the Jeypore, Malkanagiri and Naurangpur taluks where at certain places the rainfall even exceeds 75". The next part of heavy rainfall is the '3,000 ft. plateau itself', i.e., the Koraput, Pottangi and Podwa taluks where the average rainfall is about 60". The lowest area of rainfall is the Parvathipur Agency comprising the taluks of Bissamcuntack, Gunupur and Rayagada where there is only an average rainfall of about 47" (Francis, *loc. cit.*, pp. 146-7).

The natural ecological conditions of the streams of the Orissa hills are almost identical with those of the Himalayas though the thick jungle cover of the Orissa hills is being rapidly destroyed and altered and its place taken by 'Podu' cultivation in recent years. Naturally one expects to find the rivers and streams of this area harbouring typical hill-stream fishes of the Himalayas, but the collection is very remarkable for their total absence.

EARLIER RECORDS OF FISHES FROM THE ORISSA HILLS AND EASTERN GHATS.

The earliest record of fish from this region is by Day (1878) who gave the following 88 species either as known from Orissa or widely distributed in the continent of India.

List of species recorded by Day from the Eastern Ghats.

- | | |
|---|--|
| 1. <i>Notopterus chitala</i> (Ham.) | 18. <i>Amblypharyngodon mola</i> (Ham.) |
| 2. <i>Gadusia chapra</i> (Ham.) | 19. <i>Amblypharyngodon microlepis</i> (Blkr.) |
| 3. <i>Chela bacaila</i> (Ham.) | 20. <i>Aspidoparia morar</i> (Ham.) |
| 4. <i>Chela gora</i> (Ham.) | 21. <i>Barbus (Puntius) ambassis</i> (Day) |
| 5. <i>Chela phulo</i> (Ham.) | 22. <i>Barbus (Puntius) amphibioides</i> (C.V.) |
| 6. <i>Chela untrahi</i> Day | 23. <i>Barbus (Puntius) chagunio</i> (Ham.) |
| 7. <i>Laubuca atpar</i> (Ham.) | 24. <i>Barbus (Puntius) chola</i> (Ham.) |
| 8. <i>Laubuca laubuca</i> (Ham.) | 25. <i>Barbus (Puntius) conchonioides</i> (Ham.) |
| 9. <i>Barilius barila</i> (Ham.) | 26. <i>Barbus (Puntius) gelius</i> (Ham.) |
| 10. <i>Barilius barna</i> (Ham.) | 27. <i>Barbus (Puntius) phutunio</i> (Ham.) |
| 11. <i>Barilius bendelisis</i> (Ham.) | 28. <i>Barbus (Puntius) sarana</i> (Ham.) |
| 12. <i>Barilius bola</i> (Ham.) | 29. <i>Barbus (Puntius) sophore</i> (Ham.) |
| 13. <i>Danio devario</i> (Ham.) | 30. <i>Barbus (Puntius) terio</i> (Ham.) |
| 14. <i>Danio (Brachydanio) rerio</i> (Ham.) | 31. <i>Barbus (Puntius) tetrapagrus</i> McClell. |
| 15. <i>Eleomus danrica</i> (Ham.) | 32. <i>Barbus (Puntius) ticto</i> (Ham.) |
| 16. <i>Rasbora rasbora</i> (Ham.) | 33. <i>Barbus (Tor) ? khudree</i> (Sykes) |
| 17. <i>Rasbora daniconius</i> (Ham.) | 34. <i>Catla, catla</i> (Ham.) |

List of species recorded by Day from the Eastern Ghats—(Continued.)

- | | |
|---|--|
| 35. <i>Cirrhitina reba</i> (Ham.) | 62. <i>Pangasius pangasius</i> (Ham.) |
| 36. <i>Crossocheilus latius latius</i> (Ham.) | 63. <i>Ailia coila</i> (Ham.) |
| 37. <i>Garra lamta</i> (Ham.) | 64. <i>Clupisoma garua</i> (Ham.) |
| 38. <i>Labeo angra</i> (Ham.) | 65. <i>Eutropichthys vacha</i> (Ham.) |
| 39. <i>Labeo bata</i> (Ham.) | 66. <i>Pseudeutropius atherinoides</i> (Bloch) |
| 40. <i>Labeo calbasu</i> (Ham.) | 67. <i>Eutropichthys murius</i> (Ham.) |
| 41. <i>Labeo fimbriatus</i> (Bloch) | 68. <i>Heteropneustes fossilis</i> (Bloch) |
| 42. <i>Labeo gonius</i> (Ham.) | 69. <i>Clarias batrachus</i> (Linn.) |
| 43. <i>Labeo rohita</i> (Ham.) | 70. <i>Anguilla bengalensis</i> (Ham.) |
| 44. <i>Rohitee cotio</i> (Ham.) | 71. <i>Panchax melanostigma</i> (McClell.) |
| 45. <i>Lepidocephalichthys guntea</i> (Ham.) | 72. <i>Panchax panchax</i> (Ham.) |
| 46. <i>Nemachilus botia</i> (Ham.) | 73. <i>Xenentodon cancila</i> (Ham.) |
| 47. <i>Nemachilus beavani</i> Gunther | 74. <i>Ophicephalus gachua</i> Ham. |
| 48. <i>Nemachilus zonatus</i> (McClell.) | 75. <i>Ophicephalus marulius</i> Ham. |
| 49. <i>Callichrous bimaculatus</i> (Bloch) | 76. <i>Ophicephalus punctatus</i> (Bloch) |
| 50. <i>Callichrous pabda</i> (Ham.) | 77. <i>Ophicephalus striatus</i> (Bloch) |
| 51. <i>Wallago attu</i> (Bl. & Sch.) | 78. <i>Ambassis baculis</i> (Ham.) |
| 52. <i>Mystus aor</i> (Ham.) | 79. <i>Ambassis nama</i> (Ham.) |
| 53. <i>Mystus cavasius</i> (Ham.) | 80. <i>Ambassis ranga</i> (Ham.) |
| 54. <i>Mystus corsula</i> (Ham.) | 81. <i>Anabas testudineus</i> (Bloch) |
| 55. <i>Mystus gulio</i> (Ham.) | 82. <i>Badis badis</i> (Ham.) |
| 56. <i>Mystus tengara</i> (Ham.) | 83. <i>Nandus nandus</i> (Ham.) |
| 57. <i>Mystus vittatus</i> (Bloch) | 84. <i>Glossogobius giuris</i> (Ham.) |
| 58. <i>Rita chrysea</i> Day | 85. <i>Mastacembelus armatus</i> (Lacép.) |
| 59. <i>Bagarius bagarius</i> (Ham.) | 86. <i>Mastacembelus pancalus</i> (Ham.) |
| 60. <i>Hara hara</i> (Ham.) | 87. <i>Rhyncobdella aculeata</i> (Bloch) |
| 61. <i>Gagata cenia</i> (Ham.) | 88. <i>Amphiprion cuchia</i> (Ham.) |

Of the above 88 species, *Nemachilus beavani* is restricted to Eastern Himalayas (Hora, 1935), *N. zonatus* to Assam and Rajmahal Hills (Hora, 1938) and *Garra lamta* to the Eastern parts of the Vindhya range and the Nepal Terai (Hora, 1921); *Callichrous pabda* is synonymous with *Callichrous bimaculatus* (Hora, 1936). Day's *Barbus tor* (Ham.) and *Erethistes hara* may be referable here to *Barbus* (*Tor*) *khudree* (*vide infra*) and *Hara hara* (Ham.) (Hora, 1949b), as these are the species known to occur in Orissa. The total number of species in the above list is, thus, reduced to 84.

The next record of fish from the Eastern Ghats is by Misra (1938). The material on which his report is based was obtained by Dr. H. S. Pruthi from the various mountain ranges of the Eastern Ghats lying below the Kistna river. It comprised 37 species of which the following species were not previously recorded by Day from this region:

- | | |
|---|---------------------------------------|
| 85. <i>Notopterus notopterus</i> (Pallas) | 92. <i>Esomus barbatus</i> (Jerdon) |
| 86. <i>Chela clupeoides</i> (Bloch) | 93. <i>Garra mullya</i> (Sykes) |
| 87. <i>Danio aequipinnatus</i> (Ham.) | 94. <i>Rohitee duvaucelli</i> (C.V.) |
| 88. <i>Barbus</i> (<i>Puntius</i>) <i>dorsalis</i> (Jerdon) | 95. <i>Nemachilus striatus</i> Day |
| 89. <i>Barbus</i> (<i>Puntius</i>) <i>filamentosus</i> (C.V.) | 96. <i>Panchax lineatus</i> (C.V.) |
| 90. <i>Barbus</i> (<i>Puntius</i>) <i>melanampyx</i> (Day) | 97. <i>Etroplus maculatus</i> (Bloch) |
| 91. <i>Cirrhitina fulungee</i> (Sykes) | |

In the same year Hora (1938a, pp. 237-41) reported on a collection of fish made from the Bailadila range, Bastar State, C.P. This report makes the following new additions to the Eastern Ghats:

- | | |
|---|---|
| 98. <i>Barbus</i> (<i>Puntius</i>) <i>pinnauratus</i> (Day) | 101. <i>Nemachilus dayi</i> (Hora) |
| 99. <i>Parapsilorhynchus tentaculatus</i> (Annand.) | 102. <i>Nemachilus ezeardi</i> Day |
| 100. <i>Nemachilus botia</i> var. <i>aureus</i> Day | 103. <i>Glyptothorax dekkannensis</i> (Gunther) |

Hora (1940, pp. 365-74) in his report 'On a collection of fish from the headwaters of the Mahanadi' further added to the previous list the following species:

- | | |
|--|--------------------------------------|
| 104. <i>Labeo boggut</i> (Sykes) | 106. <i>Nemachilus denisonii</i> Day |
| 105. <i>Oreichthys cosuatus</i> (Ham.) | 107. <i>Amblyceps mangois</i> (Ham.) |

The next account of fish from this region is by Chauhan (1947). His list contains 54 species, of which new additions are as follows:

- | | |
|---|---|
| 108. <i>Gonialosa manminna</i> (Ham.) | 114. <i>Rohitee cotio</i> var. <i>cunma</i> Day |
| 109. <i>Chela boopis</i> Day | 115. <i>Rohitee vigorii</i> Sykes. |
| 110. <i>Danio chrysops</i> (C.V.) | 116. <i>Glyptothorax lonah</i> (Sykes) |
| 111. <i>Danio malabaricus</i> (Jerdon) | 117. <i>Mystus seenghala</i> (Sykes) |
| 112. <i>Barbus (Puntius) guganio</i> (Ham.) | 118. <i>Mugil corsula</i> (Ham.) |
| 113. <i>Labeo ariza</i> (Ham.) | |

The following species occurring in the material under report is recorded here for the first time from the Eastern Ghats:

- 119. *Sicyopterus griseus* (Day)

Recently in February-March, 1951, Mr. B. Biswas, Officer-in-Charge, Bird Section, Zoological Survey of India, during a survey of the Simlipal hills, Mayurbhanj (Orissa) with special reference to the bird fauna made a representative collection of fish from the area. This collection, however, does not make any new addition to the fish fauna of the Eastern Ghats.

Combining all the above lists, there are in all 119 species. Of these, *Danio malabaricus* (Jerdon) and *Rohitee duvaucelli* (C.V.) are synonymous with *Danio aequipinnatus* (McClell.) (Hora, 1941) and *Rohitee cotio* var. *cunma* Day (Hora and Misra, 1940) respectively. *Etioplus maculatus* (Bloch) belonging to the family Cichlidae represents the Ethiopian element in the fauna (Hora, 1937) and has, therefore, not been taken into consideration for the present discussion. Of the 84 species recorded by Day (*op. cit.*), either as known from Orissa or widely distributed in the continent of India, the following were not represented in any of the later collections nor are they present in the collection under report:

- | | |
|---|---|
| 1. <i>Notopterus chitala</i> (Ham.) | 13. <i>Labeo angra</i> (Ham.) |
| 2. <i>Chela phulo</i> (Ham.) | 14. <i>Labeo rohita</i> (Ham.) |
| 3. <i>Chela untrahi</i> Day | 15. <i>Mystus corsula</i> (Ham.) |
| 4. <i>Laubuca atpar</i> (Ham.) | 16. <i>Mystus gulio</i> (Ham.) |
| 5. <i>Barilius bola</i> (Ham.) | 17. <i>Gagata cenia</i> (Ham.) |
| 6. <i>Barilius barila</i> (Ham.) | 18. <i>Eutropichthys murius</i> (Ham.) |
| 7. <i>Rasbora rasbora</i> (Ham.) | 19. <i>Aplochilus melanostigma</i> (McClell.) |
| 8. <i>Barbus (Puntius) chagunio</i> (Ham.) | 20. <i>Ophicephalus marulius</i> (Ham.) |
| 9. <i>Barbus (Puntius) ambassis</i> (Day) | 21. <i>Ailia coila</i> (Ham.) |
| 10. <i>Barbus (Puntius) phutunio</i> (Ham.) | 22. <i>Pangasius pangasius</i> (Ham.) |
| 11. <i>Barbus (Puntius) terio</i> (Ham.) | 23. <i>Amphipnous cuchia</i> (Ham.) |
| 12. <i>Catla catla</i> (Ham.) | |

The above species may or may not be found in the Orissa hills and the Eastern Ghats, but as they are not of any importance from the point of view of the zoogeographical discussion, being mainly sluggish water forms, they have been omitted. The total number, therefore, is reduced to 93 species. From the earlier accounts (*op. cit.*) and also from my own extensive collections from this region, I have been able to make out the following table showing the distribution of species in the various drainage systems of the Eastern Ghats.

From the above list, it is evident that there are 21 families, 46 genera and 93 species of fishes so far known from the Orissa hills and the Eastern Ghats. Of these, 47 species belong to the family Cyprinidae, 1 to Clupeidae, 1 to Dorosomidae, 7 to Cobitidae, 2 to Siluridae, 7 to Bagridae, 1 to Amblycepidae, 4 to Sisoridae, 3 to Schilbeidae, 1 to Heteropneustidae, 1 to Clariidae, 2 to Cyprinodontidae, 1 to Mugilidae, 1 to Belonidae, 3 to Ophicephalidae, 2 to Percidae, 1 to Anabantidae, 2 to Nandidae, 2 to Gobiidae, and 3 to Mastacembelidae.

It is also clear that more than half of the fish-fauna of the Eastern Ghats belongs to the family Cyprinidae. Further, none of the typical torrential genera of fishes of the Eastern Himalayas, like *Pseudeucheneis* Blyth, *Exostoma* Blyth, *Euchiloglanis* Regan, *Balitor* Gray and *Psilorhynchus* McClell. occurs in the fauna of the

LIST OF FISHES KNOWN FROM THE ORISSA HILLS AND THE EASTERN GHATS WITH THEIR DISTRIBUTION.

Name of Species.	DRAINAGE SYSTEMS.						Further distribution.
	Mahanadi river.	Vamsa-dhara river.	Nagavali river.	Godavari river.	Penner river.	Palar river.	
Family: <i>NOTOPTERIDAE</i>							
1. <i>Notopterus notopterus</i> (Pallas)	+	+	+	+	+	+	Widely distributed in India, Burma and further east.
Family: <i>CLUPEIDAE</i>							
2. <i>Gadusia chapra</i> (Ham.)	+	-	-	-	-	-	Widely distributed in N. India; absent below Kistna in the south.
Family: <i>DOROSOMIDAE</i>							
3. <i>Goniadon marminna</i> (Ham.)	+	-	-	-	-	-	Fresh waters of Sind and the drainage systems of the Indus, Ganges, Brahmaputra and the Mahanadi.
Family: <i>CYPRINIDAE</i>							
Sub-fam.: <i>ABRAMADINAE</i>							
4. <i>*Chela bacaila</i> (Ham.)	+	-	+	-	+	-	Throughout India (except Malabar) and Burma.
5. <i>Chela boopis</i> Day	+	-	-	-	-	-	Central and Northern divisions of the Western Ghats and Kaimur hills on the Satpura-Vindhya trend.
6. <i>Chela clupeoides</i> (Bloch)	+	-	-	-	+	-	Peninsular India, Cutch, Pachmarhi hills and the Chota-Nagpur plateau on the Vindhya-Satpura trend and Burma.
7. <i>*Chela gora</i> (Ham.)	+	-	-	-	-	-	Sind throughout Northern India and Assam.
8. <i>Laubuca laubuca</i> (Ham.)	+	-	-	-	-	-	All over Northern India, Assam and Burma.
Sub-fam.: <i>RABSORINAE</i>							
9. <i>Borilius barna</i> (Ham.)	+	-	-	-	-	-	All over Northern India and Burma, absent below Kistna in the south.
10. <i>Borilius bendelisis</i> (Ham.)	+	-	-	-	-	-	Fairly widely distributed in India.
11. <i>Borilius vagra</i> (Ham.)	+	-	-	-	-	-	Throughout Northern India.
12. <i>*Dentio acquirivinnatus</i> (McClell.)	+	+	+	+	+	+	Ceylon, India, Burma and Siam.
13. <i>*Dentio (Brachydania) rerio</i> (Ham.)	+	+	+	+	+	?	Throughout India and Burma.

LIST OF FISHES KNOWN FROM THE ORISSA HILLS AND THE EASTERN GHATS WITH THEIR DISTRIBUTION—Continued.

Name of Species.	DRAINAGE SYSTEMS.					Further distribution.
	Mahanadi river.	Vamsa-dhara river.	Nagavali river.	Godavari river.	Penner river.	Palar river.
35. * <i>Barbus (Tor) khudree</i> (Sykes)	+	—	+	+	—	—
36. <i>Cirrhitina fulunges</i> Sykes	..	—	—	—	+	—
37. <i>Cirrhitina reba</i> (Ham.)	..	—	—	—	+	—
38. * <i>Crossocheilus latius latius</i> (Ham.)	..	—	—	+	—	—
39. * <i>Garra mullia</i> (Sykes)	+	+	+	+	+	?
40. <i>Laboe oriza</i> (Ham.)	+	—	—	—	—	—
41. <i>Laboe bata</i> (Ham.)	..	—	—	—	+	—
42. <i>Laboe bogrus</i> (Sykes)	..	—	—	—	—	—
43. <i>Laboe calbasu</i> (Ham.)	..	—	—	—	—	—
44. <i>Laboe fimbriatus</i> (Bloch)	..	—	—	—	+	?
45. <i>Laboe gonius</i> (Ham.)	..	—	—	—	—	—
46. <i>Oreochelys coarctatus</i> (Ham.)	..	—	—	—	—	—
47. <i>Parapsilorhynchus tentaculatus</i> (Anandale)	..	—	—	—	—	—
48. <i>Rohites cotio</i> (Ham.)	..	—	—	—	—	—
49. <i>Rohites cotio</i> var. <i>cumma</i> Day	+	—	—	—	—	?

Ceylon, Peninsular India, and Pachmarhi and Kaimur hills on the Satpura-Vindhya trend. Deccan and Mysore. Throughout India. Bombay ghat portion of the Western Ghats, Kaimur hills, and the Chotanagpur plateau on the Vindhya-Satpura trend and E. Himalayas. Peninsular India, Pachmarhi and Kaimur hills and the Chota-Nagpur plateau on the Satpura-Vindhya trend. Nilgiris, Wynad and Mysore. Kistna and Godavari rivers, Orissa, Bengal and Assam. Peninsular India, C.P. (Satpura and Vindhyas), and also Malaya; its record from Punjab requires confirmation. India and Burma; it has also been recorded from China. S. India (except Malabar), Deccan, S. Sind, Punjab. India and Burma; absent below Kistna in the south. India, Burma and also Siam. Bombay ghat portion of the Western Ghats and Pachmarhi hills on the Satpura-Vindhya trend. Northern India and Assam. Peninsular India, Orissa, Assam and Burma.

LIST OF FISHES KNOWN FROM THE ORISSA HILLS AND THE EASTERN GHATS WITH THEIR DISTRIBUTION—Continued.

Name of Species.	DRAINAGE SYSTEMS.						Further distribution.
	Mahanadi river.	Vamsa-dhara river.	Nagavali river.	Godavari river.	Penner river.	Palar river.	
70. <i>Glyptothorax lonah</i> (Sykes) ..	+	—	—	—	—	—	Deccan.
71. <i>Hara hara</i> (Ham.) ..	+	—	—	—	—	—	Assam, Bengal, Bihar, and U.P.
Family: SCHILBEIDAE							
72. <i>Clupeoma garua</i> (Ham.)	+	—	—	—	—	—	Sind, all over Northern India, Assam and Burma.
73. <i>Eutropichthys vacha</i> (Ham.)	+	—	—	—	—	—	Punjab, Sind, Bengal, Orissa, Burma and Siam.
74. <i>Pseudotropius atherinoides</i> (Bloch)	+	—	—	—	—	—	India and Burma.
Family: HETEROPNEUSTI- DAE							
75. <i>Heteropneustes fossilis</i> (Bloch)	+	—	—	—	+	+	Ceylon, India, Burma and Cochinchina.
Family: CLARIIDAE							
76. * <i>Clarias batrachus</i> (Linn.) ..	+	+	+	+	+	?	India, Burma and further east.
Family: CYPRINODONTI- DAE							
77. <i>Panchax lineatus</i> (C.V.)	—	—	—	—	+	?	Ceylon and Peninsular India.
78. <i>Panchax panchax</i> (Ham.)	—	—	—	—	+	?	India, Assam and Burma.
Family: MUGILIDAE							
79. <i>Mugil coreula</i> (Ham.)	+	—	—	—	—	—	Northern India and Assam.
Family: BELONIDAE							
80. <i>Xenentodon cancila</i> (Ham.)	+	—	—	+	—	—	Ceylon, India, Burma and further east.
Family: OPHICEPHALI- DAE							
81. * <i>Ophicephalus gachua</i> Ham.	+	+	+	+	+	+	Ceylon, India, Burma and further east.

82. * <i>Ophecephalus punctatus</i> (Bloch)	+	-	-	+	+	+	+	India, Burma and Malaya.
83. <i>Ophecephalus striatus</i> (Bloch)	-	-	-	-	-	-	-	Ceylon, India, Burma and further east.
Family: PERCIDÆ								
84. <i>Ambassis baculis</i> Ham.	+	+	-	-	-	-	-	All over Northern India and Burma.
85. <i>Ambassis ranga</i> (Ham.)	..	..	-	-	-	-	-	India, Burma and Siam.
Family: ANABANTIDÆ								
86. * <i>Anabas testudineus</i> (Bloch)	-	-	-	-	+	-	-	Ceylon, India, Burma and further east.
Family: NANDIDÆ								
87. <i>Ecdia badis</i> (Ham.)	+	+	-	-	-	-	-	India and Burma.
88. <i>Nandus nandus</i> (Ham.)	..	..	-	-	-	-	-	India, Burma and Siam.
Family: GOBIIDÆ								
89. * <i>Glossogobius giuris</i> (Ham.)	+	-	-	+	+	-	-	India, Burma and further east.
90. * <i>Sicyopterus griseus</i> (Day)	..	..	-	-	-	-	-	South Canara and Travancore.
Family: MASTACEMBELIDÆ								
91. <i>Mastacembelus armatus</i> (Lacép.)	+	+	-	+	+	-	-	Ceylon, India, Burma and further east.
92. <i>Mastacembelus pancalus</i> (Ham.)	+	+	-	-	-	-	-	All over Northern India.
93. <i>Rhynobdella aculeata</i> (Bloch)	+	+	-	+	+	-	-	Common in the deltaic regions of Northern India.

* Species represented in the collection under report.

Eastern Ghats. Besides this fact, it is also abundantly clear that such genera as *Crossocheilus*, *Parapsilorhynchus*, *Amblyceps*, *Glyptothorax*, and *Hara* are limited to the northern portion mainly drained by the Godavari and the Mahanadi and do not occur in the south. From this state of distribution it would appear that the discontinuous line of hills of the Eastern Ghats is not a contiguous zoogeographical unit, and is divisible into the following two major divisions:

- (1) the part lying above the Godavari river which can be termed for the purpose of description the Orissa hills and
- (2) the other lying below the Kistna river for which the term Eastern Ghats can be more appropriately used.

It may be mentioned in this connection that between the rivers of the Godavari and the Kistna there are no hill-ranges combining the above two zoogeographical divisions.

Judging from the table of distribution given above it is evident that the fish-fauna of the Mahanadi basin is, in the main, Gangetic and that this does not appear to occur in the drainage systems below it except to a small extent in the Godavari. *Amblyceps* and *Hara*, common to the Ganges and the Mahanadi drainage systems do not occur in the Godavari. On the contrary, *Parapsilorhynchus* and *Crossocheilus* are seen only in the portion drained by the Godavari and nowhere else in the Orissa hills or the Eastern Ghats. It appears to me, from the above facts, that the Orissa hills can be further sub-divided into:

- (a) the northern portion drained mainly by the Mahanadi, and
- (b) the southern portion drained by the Indravati, the Kolab and the Matchkund, the three important tributaries of the Godavari draining the Orissa hills.

ZOOGEOGRAPHICAL AFFINITIES OF THE FISHES OF THE ORISSA HILLS AND THE EASTERN GHATS.

The fish-fauna of the Eastern Ghats can be divided into the following groups from a zoogeographical point of view:

Group I.

- | | |
|---|---|
| 1. <i>Notopterus notopterus</i> (Pallas) | 23. <i>Mystus cavasius</i> (Ham.) |
| 2. <i>Chela bacaila</i> (Ham.) | 24. <i>Mystus seenghala</i> (Sykes) |
| 3. <i>Labeo laubuca</i> (Ham.) | 25. <i>Mystus vittatus</i> (Bloch) |
| 4. <i>Barilius barna</i> (Ham.) | 26. <i>Bagarius bagarius</i> (Ham.) |
| 5. <i>Danio aequipinnatus</i> (McClell.) | 27. <i>Clupisoma garua</i> (Ham.) |
| 6. <i>Danio (Brachydanio) rerio</i> (Ham.) | 28. <i>Eutropiichthys vacha</i> (Ham.) |
| 7. <i>Rasbora daniconius</i> (Ham.) | 29. <i>Pseudotropius atherinoides</i> (Bloch) |
| 8. <i>Amblypharyngodon mola</i> (Ham.) | 30. <i>Heteropneustes fossilis</i> (Bloch) |
| 9. <i>Barbus (Puntius) chola</i> (Ham.) | 31. <i>Clarias batrachus</i> (Linn.) |
| 10. <i>Barbus (Puntius) pinnauratus</i> (Day) | 32. <i>Panchax panchax</i> (Ham.) |
| 11. <i>Barbus (Puntius) sarana</i> (Day) | 33. <i>Xenentodon cancila</i> (Ham.) |
| 12. <i>Barbus (Puntius) sophore</i> (Ham.) | 34. <i>Ophicephalus gachua</i> (Ham.) |
| 13. <i>Barbus (Puntius) ticto</i> (Ham.) | 35. <i>Ophicephalus punctatus</i> (Bloch) |
| 14. <i>Labeo calbasu</i> (Ham.) | 36. <i>Ophicephalus striatus</i> (Bloch) |
| 15. <i>Labeo gonius</i> (Ham.) | 37. <i>Ambassis baculis</i> (Ham.) |
| 16. <i>Oreichthys coelestis</i> (Ham.) | 38. <i>Ambassis ranga</i> (Ham.) |
| 17. <i>Lepidocephalichthys guntea</i> (Ham.) | 39. <i>Anabas testudineus</i> (Bloch)! |
| 18. <i>Nemachilus botia</i> (Ham.) | 40. <i>Badis badis</i> (Ham.) |
| 19. <i>Callichrous bimaculatus</i> (Bloch) | 41. <i>Nandus nandus</i> (Ham.) |
| 20. <i>Wallago attu</i> (Bl. Schn.) | 42. <i>Glossogobius giuris</i> (Ham.) |
| 21. <i>Mystus aor</i> (Ham.) | 43. <i>Mastacembelus armatus</i> (Lacép.) |
| 22. <i>Mystus bleekeri</i> (Day) | |

The above species are widely distributed in the Oriental region and are, therefore, of little importance from the point of view of the Satpura problem of distribution of the fish-fauna.

Group II.

1. *Barilius bendelisis* (Ham.)
2. *Cirrhitina reba* (Ham.)

This group consists of species widely distributed in India and do not throw any light on the zoogeographical affinity of the Eastern Ghats.

Group III.

1. *Gadusia chapra* (Ham.)
2. *Goniistius manminna* (Ham.)
3. *Chela gora* (Ham.)
4. *Danio devario* (Ham.)
5. *Esomus danricus* (Ham.)
6. *Aspidoparia morar* (Ham.)
7. *Barilius vagra* (Ham.)
8. *Barbus (Puntius) conchoni* (Ham.)
9. *Barbus (Puntius) gunganio* (Ham.)
10. *Barbus (Puntius) tetrapagus* (McClell.)
11. *Rohitee cotio* (Ham.)
12. *Mastacembelus pancalus* (Ham.)
13. *Rhynobdella aculeata* (Bloch)
14. *Mystus tengara* (Ham.)
15. *Mugil corsula* (Ham.)
16. *Hara hara* (Ham.)

Species of this group are widely distributed in Northern India. Of these, excepting *Esomus danricus* (Ham.) and *Rhynobdella aculeata* (Bloch), the others do not extend south of the river Mahanadi. Even these two species are more common in the north of the river Mahanadi than in the south. This is suggestive of a close affinity of the fish-fauna of the Mahanadi to that of the fishes of the Gangetic system of drainage.

Group IV.

1. *Amblyceps mangois* (Ham.)
2. *Crossocheilus latius latius* (Ham.)

Species belonging to this group are distributed in the Himalayas and further east on the one hand and in the Satpura trend of mountains on the other. This distribution of these species is indicative of the relationship of the fauna of the Orissa hills to the Satpura trend of mountains and suggests that the Orissa hills are only spurs of the once extensive Satpura trend of mountains.

Group V.

1. **Chela chupeoides* (Bloch)
2. †*Barbus (Puntius) amphibi* (C.V.)
3. †*Barbus (Puntius) dorsalis* (Jerdon)
4. *Garra mullia* (Sykes)
5. *Labeo boggut* (Sykes)
6. †*Barbus (Tor) khudree* (Sykes)

Group V consists of forms found in the Chota-Nagpur plateau, the Vindhya, the Satpuras, and Peninsular India including the Western Ghats. A close affinity of the fish-fauna of the Orissa hills and the Eastern Ghats to the Satpura trend of mountains, the Western Ghats and the hills of Peninsular India is indicated by the distribution of the above species.

Group VI.

1. *Chela boopis* Day
2. *Nemachilus dayi* Hora
3. *Nemachilus denisonii* Day

The above forms are found in the Chota-Nagpur plateau, the Vindhya, the Satpuras and the central and northern divisions of the Western Ghats. This group also indicates the close kinship of the fauna of the Eastern Ghats to the Satpura trend of mountains and the northern and central portions of the Western Ghats.

* Also found in Cutch.

† Widely distributed in Ceylon.

Group VII.

1. *Parapsilorhynchus tentaculatus* (Ann.)
2. *Nemachilus evezardi* Day

These two species are distributed in the Satpuras and the northern section of the Western Ghats. Unmistakable evidence of the close affinity of the Orissa hills to the Satpura mountains and the northern section of Western Ghats is afforded by the distribution of the above species.

Group VIII.

- | | |
|--|-----------------------------------|
| 1. <i>Glyptothorax dekkanensis</i> (Günther) | 4. <i>Rita chrysea</i> Day |
| 2. <i>Glyptothorax lonah</i> (Sykes) | 5. <i>Labeo ariza</i> (Ham.) |
| 3. <i>Cirrhitina fulurges</i> (Sykes) | 6. <i>Nemachilus striatus</i> Day |

The above species found in the northern and central divisions of the Western Ghats indicate a kinship of the fauna of the Eastern Ghats to that of the Western Ghats, especially the northern section of it.

Group IX.

- | | |
|--|---|
| 1. <i>Esomus barbatus</i> (Jordan) | 5. <i>Rohtee vigorsii</i> (Sykes) |
| 2. <i>Barbus (Puntius) filamentosus</i> (C.V.) | 6. <i>Nemachilus botia</i> var. <i>aureus</i> Day |
| 3. <i>Barbus (Puntius) melanampyx</i> (Day) | 7. <i>Panchax lineatus</i> (C.V.) |
| 4. <i>Labeo fimbriatus</i> (Bloch) | 8. <i>Sicyopterus griseus</i> (Day) |

The above species are restricted to Peninsular India including the Western Ghats and this offers a further evidence of the relationship of the fauna of the Orissa hills and the Eastern Ghats to that of the Western Ghats and also the hills of Peninsular India.

Group X.

- | | |
|---|--|
| 1. * <i>Danio chrysops</i> (C.V.) | 4. <i>Labeo bata</i> (Ham.) |
| 2. <i>Amblypharyngodon microlepis</i> (Blkr.) | 5. <i>Rohtee cotio</i> var. <i>cunna</i> Day |
| 3. * <i>Barbus (Puntius) gelius</i> (Ham.) | |

Species coming under this group are either restricted to Assam and Bengal or found in Assam and Bengal on the one hand and Peninsular India on the other. The dispersal of the above forms from the east to Peninsular India must have been along the Assam hills and the Satpura trend of mountains during the earlier waves of migration of the fauna to the south when the movement from N.E. to S.W. was facilitated by the presence of the necessary water connections. The present-day distribution of the above species too indirectly points to a relationship of the Orissa hills and the Eastern Ghats to the Satpura trend of mountains and the hills of Peninsular India.

It is abundantly clear from the above that the fish-fauna of the Orissa hills and the Eastern Ghats have a very close affinity with that of the Satpura-Vindhya mountains and the northern division of the Western Ghats and that there is a conspicuous absence of forms common to the fish-fauna of the Malayan region and Peninsular India (Hora, 1944, pp. 426-28) from the fauna of this region. These are evidences conclusive enough to show that the route of migrations of fishes of Peninsular India did not lie along the Orissa hills and the Eastern Ghats and that the latter had mainly derived their fish-fauna from the Satpura-Vindhya mountains and the Western Ghats, especially the northern portion of it.

* Known only from Assam-Bengal.

CHANGES IN THE DRAINAGE OF EASTERN GHATS AND ITS BEARING ON THE DISPERSAL OF FISHES.

In considering the Eastern Ghats as a route of migration of the aquatic fauna it is necessary to refer to its present-day geo-morphic features. Pascoe (1950, p. 9) has given the following account of the Eastern Ghats:—

'The range shown in most maps along the east coast of the Peninsula as the Eastern Ghats has not the same simplicity of structure or outline as the Western Ghats, it has in fact, no real individuality but is composed successively from south to north, the south-eastern fringe of the Mysore plateau, of the Yellakonda (Velikonda, Ellaconda) range along the eastern margin of the Cuddapah (Kadapah) basin, of the marginal portions of the Bastar-Jeyapore plateau, and in Ganjam of several short isolated ridges of metamorphic rocks, separated by one another by broad plains and having in reality little connection with each other. The term "Eastern Ghats" is used for the hilly country as far north as eastern Mayurbhanj.'

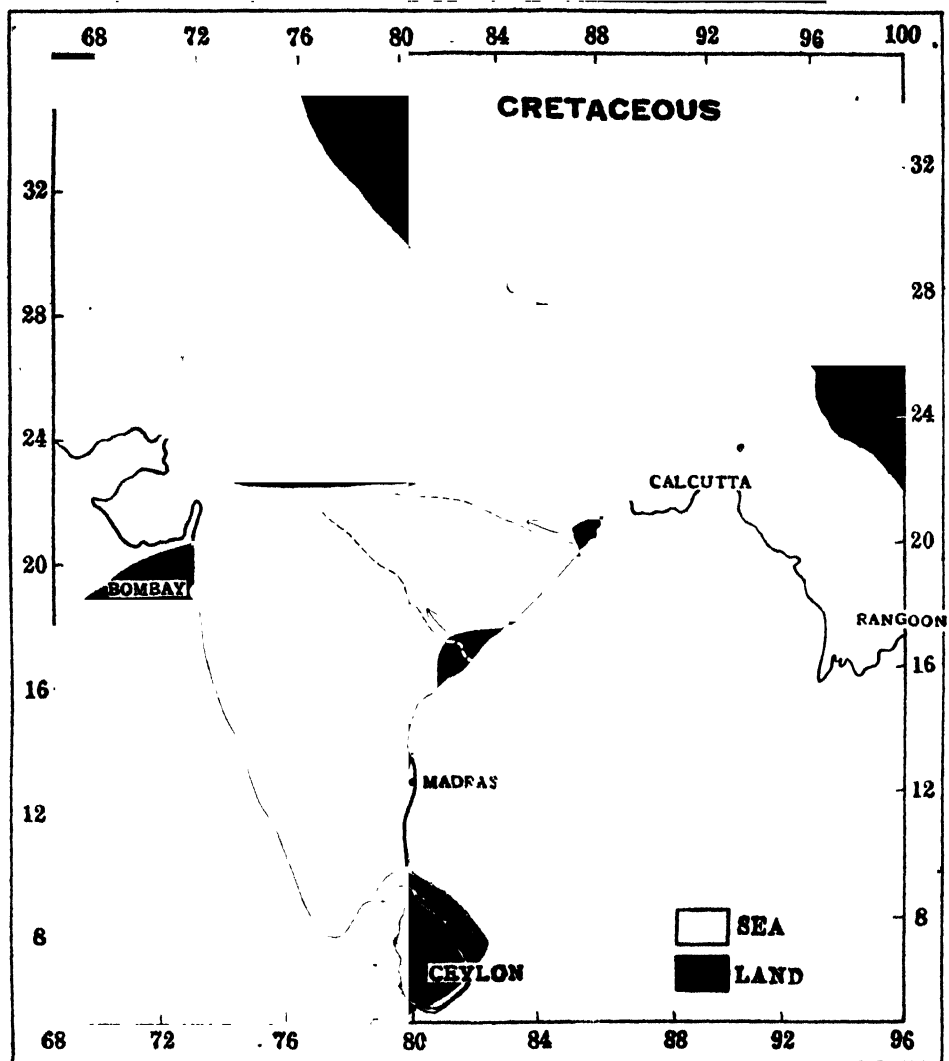
With regard to the geology of the Eastern Ghats, Pascoe (1950, p. 11) has made the following observations:—

'The so-called Eastern Ghats are too irregular and ill-defined to deserve the name of range. The southern portion is composed of the igneous rocks known as Charnockite, as is also the Nilgiri plateau which it joins and the Palni hills mentioned above, the Shevaroy hills in Salem, which are outlying portions of the Eastern Ghats, are built up of the same rocks. Traced northwards from the Eastern edge of the Mysore plateau the Eastern Ghats widen out into the forest-clad Nallamalai hills ("Black hills") of the Cuddapah and Kurnool districts, consisting of pre-Cambrian rocks named after these districts. Further north-east, they are seen to approach closer to the sea-shore until their distance from it in Ganjam and Vizagapatam is in places not more than ten or twenty miles. In this area they are made up of charnockite, and garnetiferous schists and gneisses, and have a linear arrangement coincident with axes of disturbance or folding. Although the disturbance of these rocks is not on the same scale as that which has affected the Aravalli hills, there is a distinct parallelism between the direction of the Godavari-Mahanadi section of the Eastern Ghats and the strike of pre-Cambrian folds. Whether this folding movement was in any degree directly responsible for the present relative elevation of the area, as in the case of the Aravallis is doubtful. The average height of the Eastern Ghats is about 2,000 feet, and the great Deccan tableland of the west varies usually from 1,000 to 2,000 feet.'

It will thus be seen that the Eastern Ghats represent a very ancient feature of the geography of India, geologically speaking. The drainage of this area from very ancient epochs, probably from upper Carboniferous onwards was towards north-west (Hora, 1938b, p. 398). At the close of the Gondwana epoch or probably during the early Cretaceous an arm of the sea stretched across India as far inland as Chindwara and it is very likely that the northward flowing rivers of the Peninsula may have then discharged into this gulf.

During the next epoch in the geological history, with the upheaval of the Himalayas the crack or fault that was produced along the northern part of the Peninsula (Wadia, 1939, p. 17-18) might have accentuated the shallow arm of the sea into a deep valley—the Nerbada-Tapti valley. The Godavari and the Mahanadi may have then emptied their waters into this deep-fault and gradually turned it into a purely fresh-water drainage system—the Nerbada-Tapti drainage. About the drainage of this period Hora (*loc. cit.*, p. 399-400) remarks as follows:—

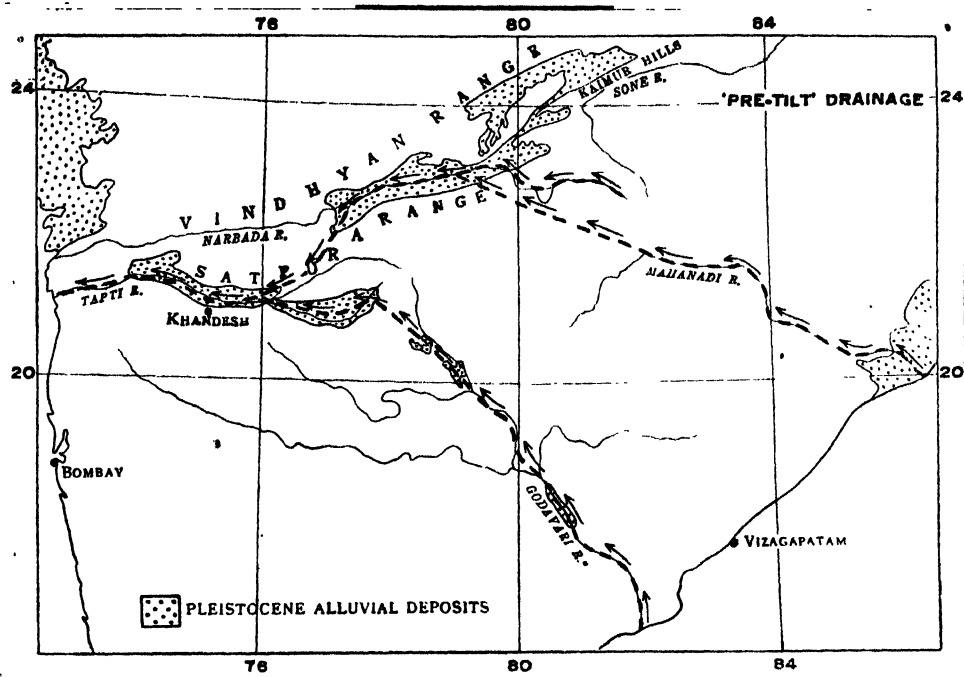
'A careful study of these fossils and the location of the beds leads one to the conclusion that in the pre-trappean period the main feature of the land surface had not undergone any very great change since the upper Gondwana period—a deep river flowed in the basin of the lower Godavari and drained north-westwards towards Rajputana. The fact that remains of *Clupea* are found at Dongargoan and Dhamnia shows that the Tethys Sea or an arm of it was not very far from these beds. Even the subsequent flows of lava that resulted in the formation of the Deccan trap, did not effect the drainage of the Peninsula to any great extent. From the small size of the *Lepidosteus* scales found in Kateru and Paharsingha, of the *Clupea* scales found at Deothan and Kheri, and the nature of the Acanthopterygian fishes of the family *Polycanthidae*, *Serranidae*, *Nandidae* and *Pristolepidae* it is safe to assume that after the lava flows the old basin became shallow and that definite estuarine conditions had become established near Deothan and Kheri. This conclusion is also



TEXT-FIG. 3. Map of India showing the distribution of land and sea during the Cretaceous (modified from a map supplied by Sir Cyril Fox to Dr. S. L. Hora on 10-11-1936).

supported by Sahni (1934) from the occurrence of the *Nepadites* palm, a typically estuarine genus, in the inter-trappean beds at Chindwara. From the above it is clear that even during the inter-trappean period the drainage of the Peninsula was towards north-west.

The Narbada-Tapti continued flowing westwards as a single river (Vredenburg, 1906, p. 40; Wadia, 1939, p. 300) with the Godavari and the Mahanadi as its tributaries till comparatively recent times in the geological history. It then facilitated the migration of the fauna from east to west while its southern tributaries did not permit the dispersal of specialised hill-stream forms to the south. The occurrence of fishes with marked Malayan affinities in the Narbada drainage (Hora and Nair, 1941, p. 369) shows that the Narbada-Tapti must have drained the Satpura trend of mountains right up to the Rajmahal hills. Considerable evidences have now been accumulated in support of the above view which will be discussed fully in a separate paper.



TEXT-FIG. 4. Map showing the probable courses of rivers in the Indian Peninsula during the 'Pre-tilt' eras (Eocene to Pleistocene). The existing rivers are marked in thin lines—the former rivers in thick bars. Arrows indicate courses of rivers.

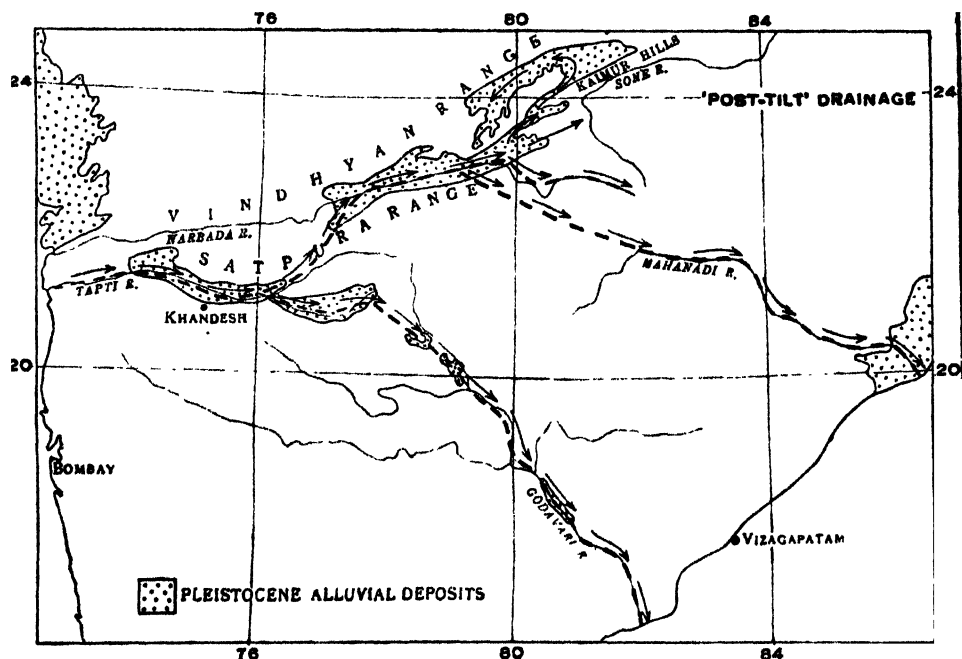
On the other hand, the absence of the typical Malayan element from the fish-fauna of the Orissa hills and the Eastern Ghats and the present-day topographic features of the Eastern Ghats (*vide supra*) lead to the conclusion that whereas plants and terrestrial animals may have spread to Peninsular India along the Eastern Ghats as well during the 'Pluvial Periods' of the Pleistocene epoch as shown in the Symposium on Satpura Hypothesis (1949, p. 363-64) the aquatic fauna, whose migration solely depends on water channels, had not taken this route for its dispersal.

There is, however, a marked affinity of the fish-fauna of the Mahanadi and to a lesser extent also that of the Godavari to the fauna of the deltaic regions of the Ganges (*vide supra*). This indicates that during the Pleistocene epoch when the Bay of Bengal did not extend as far north as at present (Oldham, 1893, p. 444; Pilgrim, 1920, p. 99) there existed a connection between these rivers at their lower portions or they had a common channel draining into the sea far below the present mouth of the Ganges. In this connection the following observations of Pilgrim regarding the extent of land along the east coast during the later epochs in the geological history is worth reiterating. He remarked (p. 99) that:

'The complicated drainage system and breadth of the Mahanadi so disproportionate to its length as well as the entire absence of any fluviatile deposits older than sub-recent, such as we find in the Irrawaddi, point to Pliocene submergence of much of its former valley and to much wider extension of the Indian Peninsula over what is now the Bay of Bengal from Eocene onward than is the case today.'

Gangetic forms are totally absent in the Kistna and the rivers below it indicating, thereby, that they had no connections whatsoever with the rivers north of them. It would also appear from the above that the Godavari is the demarcating limit between the aquatic faunas of the northern and the southern regions of India.

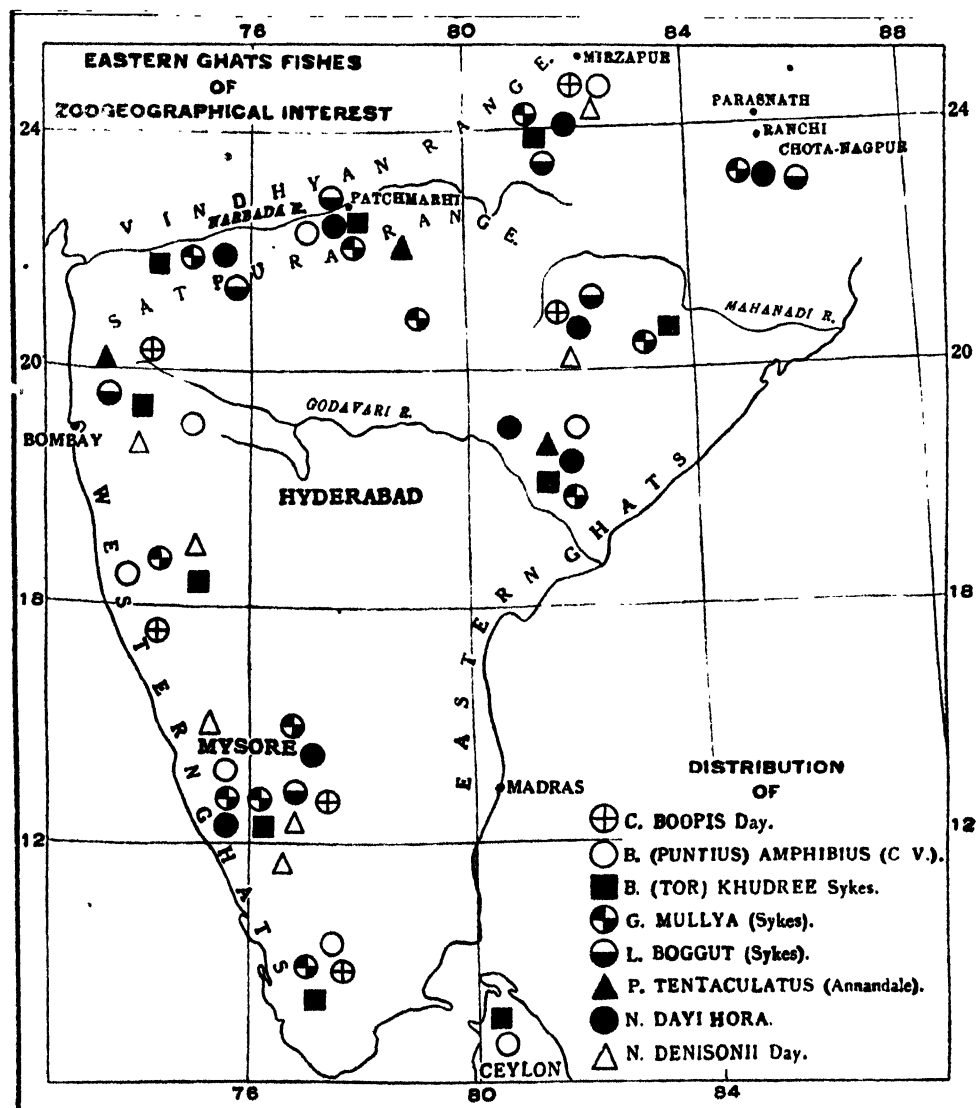
The spread of the fish-fauna to the Orissa hills and the Eastern Ghats from the Satpuras and the Western Ghats, especially the northern portion of it, seems to have been brought about by the earth-movements that affected Peninsular India and consequently reversed the north-westerly drainage of the Godavari and the Mahanadi. At what period of the geological history of India this reversal of drainage had taken place and the causes that affected it have been interesting problems of geological research and many theories have been put forward to explain it (Wadia, 1939, p. 17-18; Chhibber, 1946, p. 7). According to the most accepted explanation, the general tilting of the Peninsula¹ from west to east through the scarp faulting along the west coast in the Pleistocene (Wiseman and Sewell, 1937, p. 229-30; Heron, 1938, p. 129) would seem to account most satisfactorily the present-day easterly drainage. It is, therefore, evident that it was with the reversal of these drainages that the spread of the fish-fauna from the Western Ghats and the Satpuras to the Orissa hills and the Eastern Ghats was made possible. The absence of any endemism in the fish-fauna of the Eastern Ghats strongly supports the view that the tilting of the Peninsula and the consequent reversal of the drainage had occurred only during comparatively recent times in the geological history and sufficient time had not yet elapsed since the colonisation of fishes in the hills of the Eastern Ghats for further speciation to take place.



TEXT-FIG. 5. Map showing the probable courses of rivers in the Indian Peninsula during the 'Post-tilt' period (Pleistocene). The existing rivers are marked in thin lines—the former rivers in thick bars. Arrows indicate courses of rivers.

¹ According to Auden the Panvel flexure, which is known to extend for a distance of 200 miles from Ratnagiri district in a N.N.W. direction towards Daman, is likely to be the main tectonic feature responsible for the demarcation of the western coastline. This feature is clear and unequivocal, whereas there is no field evidence for the existence of a pronounced fault at the foot of the Western Ghats. The flexure with its associated dyke clusters probably began in the Eocene, and may have been rejuvenated during the Miocene. A feature of such prominence is considered by him to be as likely to have been connected with the still late warping of the Peninsula, which possibly continued until a later date, perhaps Quaternary (1949; 1949(a)).

It is also evident that the tilting of the Peninsula had reversed the drainage of the Narbada-Tapti for a time and thus made possible the migration of *Chela boopis*, *Garra mullya*, *Labeo boggut*, *Barbus (Puntius) amphibius*, *Barbus (Tor) khudree*, *Parapsilorhynchus tentaculatus*, *Nemachilus dayi*, *Nemachilus denisonii*, etc., forms which appear to have evolved in the northern portion of the Western Ghats, to the Satpuras through the Narbada-Tapti eastward drainage. The same reversal of the Narbada-Tapti is responsible for the occurrence of the typical fish-fauna of the hills of the Peninsula in the head-waters of the Sone river (Hora, 1949c, p. 1-7) for with the reversal of the drainage of the Narbada-Tapti its waters must have overflowed its channels and found an easy exit along the Sone into the Ganges. The present-



TEXT-FIG. 6. Outline map of Peninsular India showing the geographical distribution of *Chela boopis*, *Garra mullya*, *Labeo boggut*, *Barbus (Puntius) amphibius*, *Barbus (Tor) khudree*, *Parapsilorhynchus tentaculatus*, *Nemachilus dayi* and *N. denisonii*.

day independent river systems of the Narbada and the Tapti flowing westwards into the Arabian Sea would, thus, seem to have evolved much later in the Pleistocene after the complete exhaustion of forces that caused the tilting of the Peninsula.

CONCLUSIONS.

It can be concluded from what has been stated above, that the theory of Pleistocene Ice-Age having affected the distribution of Himalayan plants and animals to South India (Medlicott and Blanford, 1879, pp. lxx, 374-75; Oldham, 1893, pp. 14-15) cannot hold good with regard to the spread of the Malayan element in the fresh water fish-fauna of Peninsular India. Hora's view (1937a) of the possible former existence during the Tertiary era of a moderately high Satpura range along which migration is thought to have taken place continued to hold the field until Auden (1949a) gave evidence to show that a high range probably had not existed. He (Auden, *loc. cit.*, pp. 335-37), however, suggested the alternative idea of the influence of the Ice-Age in lowering evaporation and increasing run off which probably had affected the spread of the fauna to the South. Undoubtedly during the Ice-Age the increased precipitation in the Himalayas (Hora, 1950) must have considerably lessened the temperature and thereby produced a more humid condition all over the Peninsula than what the case is today. Then the forest covered humid hill-ranges of both the Western and the Eastern Ghats could serve equally well for the migration of terrestrial animals. But, water connections being the most essential factor for the dispersal of aquatic animals, it is certain that the favourable climatic changes that had prevailed all over the Peninsula during the 'Pluvial Periods' of the Pleistocene could not play any part in their distribution. The increased river discharges during the Ice-Age (Auden, *loc. cit.*) would have considerably influenced the spread of the aquatic fauna through the already existing water channels, but it is not certain whether the entire migration of this fauna had taken place during the Pleistocene. From the evolutionary history of the Narbada-Tapti it would appear that this river could serve as a highway for the migration of the aquatic fauna at a much earlier date than the Pleistocene. The total absence of the Malayan element in the fish-fauna of the Eastern Ghats points to the fact that whereas the terrestrial fauna may have migrated to the Eastern Ghats as well, the aquatic fauna had not taken this route obviously for want of water connections.

The Eastern Ghats derived their fish-fauna from the Satpura-Vindhya mountains and the northern portion of the Western Ghats during the Pleistocene earth movements that affected the Peninsula. Till then, the Godavari and the Mahanadi were flowing northwards as tributaries of the Narbada-Tapti westward flowing river. It then facilitated the migration of the aquatic fauna along the Satpura from east to west while its northward flowing tributaries did not permit the dispersal of this fauna to the south. During the Pleistocene, through the scarp-faulting along the west coast this drainage pattern was reversed and thus the dispersal of fish to the Eastern Ghats was made possible through the Godavari and the Mahanadi. Through the Narbada-Tapti eastward drainage the Western Ghats fauna got dispersed to the Satpuras and Vindhyas. The present-day independent drainage of the Narbada and Tapti rivers flowing westwards to the Arabian Sea seems to have evolved later in Pleistocene.

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STUDIES ON THE CYTOCHEMISTRY OF THE PLACENTA.

PART I.—THE OCCURRENCE AND DISTRIBUTION OF GLYCOGEN AND IRON IN THE EMBRYONIC STAGES OF AN INSECTIVORE, *CROCIDURA CAERULEA* (ANDERSON).

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(Communicated by Dr. M. A. Moghe, F.N.I.)

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1. INTRODUCTION.

It is only recently that attempts have been made to investigate the presence of certain chemical substances in the placenta of mammals by histochemical methods. The presence of lipids, glycogen, iron, alkaline and acid phosphatases, and other substances with different staining properties have been observed in Man (Dempsey and Wislocki, 1944; Wislocki and Dempsey, 1948); in rodents (Wislocki, Deane and Dempsey, 1946, and others); in the cat (Wislocki and Dempsey, 1946), in the pig (Wislocki and Dempsey, 1946); in shrews (Wislocki and Wimsatt, 1947); and in the bat, *Myotis lucifugus lucifugus* (Wimsatt, 1949).

Earlier histochemical studies were confined to lipoids and glycogen and in one instance iron (review: Wislocki, Deane and Dempsey, 1946).

The present investigation is confined to a study of the occurrence of glycogen and iron in the various foetal structures during stages of gestation of the common Indian Musk Shrew, *Crocidura caerulea* (Anderson). The work is intended to contribute towards an understanding of the functional importance of the various structures—uterine epithelium, uterine glands, yolk-sac wall, chorio-vitelline placenta and chorio-allantoic placenta—at different periods during gestation. Accounts of the occurrence of acid and alkaline phosphatases, lipids, etc., will be given in separate papers.

The structure of the placenta of *Crocidura caerulea* has been described by Sansom (1937) from material collected in India. In the following account I shall refer to the various stages of development which are identical or nearly identical with the stages described by Sansom. An animal whose embryology had already been described was deliberately chosen for this investigation so that conclusions arrived at as regards the functional importance of various structures on purely morphological grounds could be analysed by histochemical tests.

Sansom's observations on the finer structure of the placenta of *Crocidura caerulea* have been doubted by Wimsatt and Wislocki (1947) in regard to its haemochorial character. Since I have in my possession almost all stages described by Sansom, I shall redescribe the placenta of this Insectivore in a separate paper. In the following account Sansom's term 'trophoblast cells' surrounding the blood would actually mean hypertrophied maternal endothelium if Wimsatt and Wislocki's contention as regards the endotheliochorial nature of the placenta is correct.

There have been some changes in the terminology used in describing the embryological structures of mammals owing to the detailed definitions given by Mossman (1937). I have, however, used Sansom's terminology indicating changes in nomenclature wherever necessary.

2. MATERIAL AND METHODS.

Specimens of *Crocidura caerulea* were trapped in Nagpur at intervals during the course of a year. For the study of glycogen, gravid uteri were fixed in a mixture of absolute alcohol and formalin as recommended by Scott (1933). Even for iron I have obtained satisfactory results from specimens fixed in Rossman's fluid.

Sections for the study of glycogen were stained by the Bauer-Feulgen method and the Best's carmine technique with success, but the former was found to be the better of the two. Pap's silver method as modified by Mitchell and Wislocki (1944) was tried but the results were confusing due to erratic deposition of silver. In every case a control slide was prepared by treatment with saliva. The saliva was renewed a number of times during the course of half an hour and the slide was then stained by the above methods. The negative results obtained after such treatment confirmed the positive reactions obtained in slides not treated with saliva and from which glycogen was not digested. After staining, glycogen appeared in the form of violet-coloured granules of various sizes.

Iron was stained by the Turnbull blue method, Perl's ferrocyanide reaction, and the Tirmann-Schmeltzer method. Other techniques, particularly for the detection of iron as described by Cowdry (1948), by Lison (1936), by Lillie (1948), and by Gomori (1936) were also tried. But in spite of all care I did not get convincing results. The Turnbull blue method stained the whole section blue. But by replacement of hydrochloric acid by glacial acetic acid and by the use of more dilute reagents, good results were obtained. In fact, better results by the Turnbull blue method were obtained using a 4% solution of potassium ferricyanide and glacial acetic acid (2 c.c. in every 100 c.c. of the 4% ferricyanide solution), the period of time being one hour at room temperature, 90°F. The use of dilute solution at room temperature obviated the formation of erratic blue precipitate. Sections of the same stage were stained by alternative methods to ensure that the results were uniform. After staining, iron appeared in the form of blue granules but usually in the form of streaks of blue colour.

I do not think that a photomicrograph to substantiate every statement made in the text would be of value in a paper of this nature. I have made a few photographs to show the appearance presented by glycogen and iron. The granules, in some cases, are very small but they become evident under the microscope irrespective of their size.

3. CHIEF FEATURES OF THE EMBRYONIC MEMBRANES.

I have summarised below the chief features of the foetal membranes of *Crocidura* as described by Sansom (1937). This would help the reader to understand the distribution of glycogen and iron in the different stages of development:—

Implantation:—

Orientation (disc): Antimesometrial.

Orientation (first attachment): Equatorial.

Depth: Interstitial.

Decidua:* Decidua capsularis present in late stages.*

Amniogenesis: Folding.

Yolk-sac:—

Bilaminar omphalopleure: persists till full term. Reichert's membrane present between the trophoblast and the endoderm of the bilaminar omphalopleure.

* The decidua capsularis appears to be formed from folds of the uterine wall containing a stromal core derived from the sub-mucosa and not from the mucosa as in *Erinaceus*. Hence the decidua capsularis in *Erinaceus* is not quite similar to that of *Crocidura* in its origin. (Bramble and Perry, 1945.)

Chorio-vitelline placenta: poorly developed choriovitelline placenta during early stages.

Vascular splanchnopleure: invaginated over the bilaminar omphalopleure.

Chorio-allantoic placenta:—

Shape: discoid with a trophoblast sheath.

Type: labyrinthine.

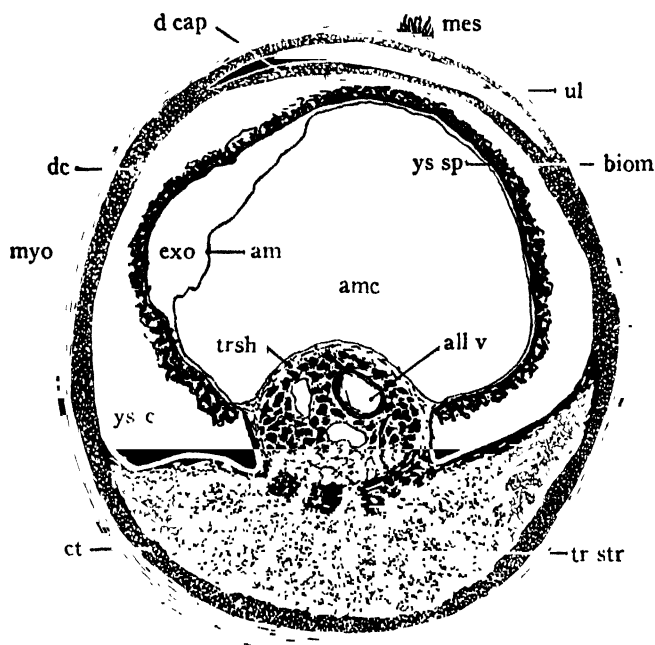
Finer morphology: haemochorial (according to Sansom).

Accessory placenta: nil.

Location: Antimesometrial.

Allantoic vesicle: absent and its place is occupied by trophoblast sheath.

A text-figure based on Sansom's photomicrograph of stage VIII (*vide* his pl. XXIX, fig. 33) is given for ready reference.



TEXT-FIG. 1. Diagrammatic representation of a transverse section through the uterus made into a line drawing from Sansom's Pl. XXIX, fig. 33, stage VIII, showing the arrangement of the foetal membranes. Allantoic vessel (*all v*), amnion (*am*), amniotic cavity (*amc*), bilaminar omphalopleure (*biom*), decidua capsularis (*d cap*), decidual cells (*dc*), exocoelom (*exo*), mesometrium (*mes*), myometrium (*myo*), trophoblastic sheath (*tr sh*), trophoblastic strands (*tr str*), uterine lumen (*ul*), yolk-sac cavity (*ys c*), yolk-sac splanchnopleure (*ys sp*).

4. SECTION I—GLYCOGEN.

(a) Observations.

I. *Endometrium*.—The uterine epithelial lining forms crypts at a very early stage of gestation (stage I). Large granules of glycogen are present in the lumen of the crypts and in the epithelial cells, particularly those on the antimesometrial side. The amount of glycogen is considerably less on the lateral and mesometrial

sides. In the next two stages (stage II and stage III), the uterine epithelium is beginning to degenerate and makes room for trophoblast cells.

The connective tissue layer persists for some time but later is invaded by the placental disc which increases in size as pregnancy advances. In stages I, II and III, glycogen is present in the connective tissue layer and in stage IV greater amount of glycogen is found in the layer on the antimesometrial side and less on the lateral and mesometrial sides. Glycogen is found round about the blood capillaries forming rings round them (fig. 2, *mbv*). This condition continues in stages V, VI, VII and VIII, the maximum quantity being observed in stage VIII. In stages IX and X, endometrium is practically lost and its place is taken by the placental disc.

In the uterine glands glycogen is absent in early stages, and they disappear during the first half of the period of gestation.

II. *Decidual cells*.—The superficial mucosa separates from the deep region of the endometrium to form a decidua lateralis. This is a wedge-shaped structure which is attached to the dome of the placenta and which is gradually eroded by the trophoblast and it is absent by stage V in my sections. Glycogen is practically absent from it from the time of its initial separation from the deep stromal tissue till it finally disappears.

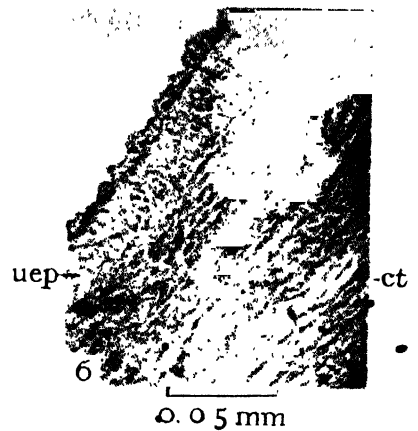
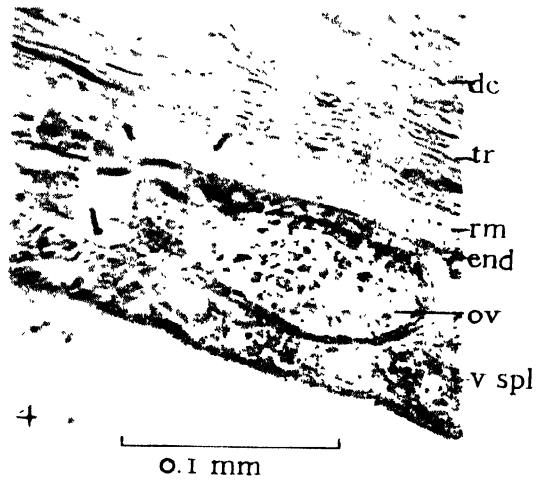
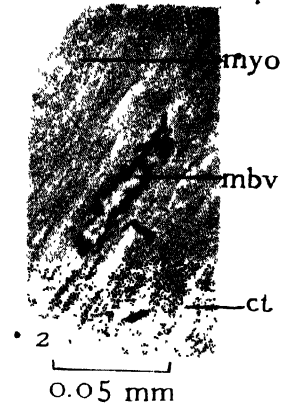
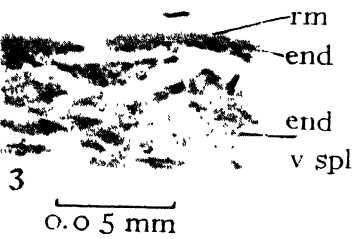
The deep stromal tissue, however, persists and the cells enlarge. The lip-like folds on the mesometrial side eventually meet and fuse in late stages to form a decidua capsularis. This deep stromal tissue always contains abundant glycogen granules. In late stages very few cells remain and even these contain glycogen. They disappear completely before parturition (figs. 3 and 4, *dc*).

III. *Trophoblast of the bilaminar omphalopleure*.—In stage I, glycogen is found in the cytoplasm of the trophoblast (Type *c* trophoblast cells; proliferating cells, according to Sansom) between the embryonal mass and the trophoblastic annulus in which it is comparatively abundant. It is very much less in the remaining trophoblast (Type *b* trophoblast cells, phagocytic and absorptive according to Sansom). In stages II and III, the trophoblast of the mesometrial and lateral sides shows the presence of glycogen and none at all on the antimesometrial side. This condition continues in stages IV, V and VI. In stage VII, very little glycogen is present and such as is present is concentrated towards the bases of the cells next to Reichert's membrane, a condition more prominently noticeable in stage VIII (fig. 3, *Tr*). In the stage before parturition, glycogen is found in the cytoplasm of some of the large vacuolated cells on the antimesometrial side opposite the placental disc particularly along the bases of the cells attached to the Reichert's membrane. In most of the trophoblast cells it is absent.

IV. *Reichert's membrane*.—This membrane first appears in stage IV and lies between the trophoblast and the endoderm cells of the bilaminar omphalopleure. In stage V, a uniform pink coloration is seen in the membrane. In stages VI, VII, VIII and IX the pink coloration is observed in some places only. In stage X no glycogen is present.

V. *Endoderm of the bilaminar omphalopleure*.—Glycogen granules seem to be absent in the endodermal cells in stages I to IV. In stages V and VI some of these cells contain glycogen. There is an increase in the size of the cells in stages VII and VIII (fig. 3, *end*) and there is a corresponding increase in the amount of glycogen. The largest number of granules which are present in these cells are seen in stage VIII when nearly all the cells are filled with them. In stages IX (fig. 4, *end*) and X the quantity of glycogen diminishes and in stage X only a few endoderm cells contain some granules.

VI. *Yolk-sac splanchnopleure*.—The yolk-sac splanchnopleure is formed by a process of partial inversion in stage IV. Few granules occur in cells near the sinus terminalis, and a large aggregate in the cells close to the foetal tissue on the mesometrial side. In stage V, the yolk-sac splanchnopleure contains a greater amount of glycogen towards the antimesometrial side, less on the lateral and almost none



on the mesometrial sides, most of the glycogen being present in the mesoderm and less in the endoderm. In stage VI, streaks and granules of glycogen appear among the endoderm cells of the villi of the yolk-sac splanchnopleure. In stage VII a few cells appear to be filled with glycogen. In stage VIII, it occurs in abundance in the cytoplasm of the cells of the endodermal villi of the yolk-sac splanchnopleure and also along the exocoelomic surface of this layer (fig. 3, *end v spl*). Smaller quantities are found in the yolk-sac cavity. In the next stage intense granular concentrations are present in the cells of the endodermal villi in the cytoplasm nearest the yolk-sac cavity (fig. 4). Glycogen is present in the walls of the omphalopleural vessels but none in the lumen. In stage X, glycogen granules occur in the yolk-sac cavity and around some omphalopleural vessels, but not in others. Glycogen is present in some endoderm cells of the endoderm villi.

VII. *The Allanto-chorionic Placenta.*—The allantoic outgrowth extends over the chorion on the antimesometrial side to form the chorio-allantoic placenta during stage IV. Allantoic mesenchyme with foetal blood-vessels penetrate the maternal tissues together with the invading trophoblast cells. Violet-coloured granules are present along the allantoic stalk, in the foetal blood and in the surrounding allantoic mesenchyme which is now commencing to spread over the placental disc. In the maternal tissues of the placental disc, glycogen granules appear to be present in the endothelium of those maternal blood capillaries where it has not been replaced by the trophoblast, and in isolated hypertrophied connective tissue cells which have yet to undergo complete destruction. In stage V and VI the distribution of glycogen is similar to the distribution in stage IV, but a new structure, the trophoblastic sheath makes its appearance on the surface of the placental dome. The sheath is composed of cytotrophoblast cells arranged in a meshwork which is continuous with the cytotrophoblastic cords which extend deep into the placental disc. The foetal blood capillaries and mesenchyme of the umbilicus pass through the mesh of the trophoblast sheath, and both contain numerous violet-coloured granules. Glycogen does not seem to be present in the cytotrophoblastic cords, and the violet granules present in this region lie in the foetal mesenchymal stroma and not in the trophoblast. Glycogen is not present in the cytotrophoblast forming the trophoblastic sheath. Trophoblast lining the maternal blood-vessels does not appear to contain glycogen though in several instances one or two granules were present in them and in the lumen of the maternal vessel. Some giant cells present at the margins of the placental rim contained glycogen in the form of fine scattered violet granules. In stage VII, glycogen is almost absent from the placental disc. Only a few granules are present in the foetal stroma. The striking abundance of violet granules in stage VIII contrast strongly with their paucity in the placental disc of the previous stage. Numerous granules are present in the lumina and walls of the maternal blood spaces and the foetal capillaries. In the surrounding foetal mesenchyme the granules are comparatively speaking very large. Much of the cytotrophoblast of the cytotrophoblastic cords has formed syncytiotrophoblast and small granules few in number are present in nearly all the trophoblast cells whether bi-nucleate or giant cells. Granules are present in cyto- or syncytio- trophoblast of the trophoblastic sheath where in previous stages glycogen was absent. Broadly speaking larger aggregates are seen at the lateral sides of the placental disc than are seen in the middle of it. Stage IX is similar to the preceding stage but the total quantity of glycogen has suffered a marked diminution. Most of the glycogen granules appear to be associated with foetal stroma. Traces were observed in the cells lining the maternal blood. Very fine granules difficult to see in the highest power of the microscope were present in syncytiotrophoblast in localized places but not all over this region, though absent more often. Glycogen granules in the lumina of the blood-vessels are still present though in lesser proportions to the preceding stage. Stage X shows a marked increase in the quantity of glycogen probably coinciding with the beginning of parturition and the degeneration of placental tissue.

VII. *Amnion*.—Glycogen is first observed in stage V. In stage VIII the number of granules is so large that the amnion itself could be traced by the rows of violet granules. It is absent in the other stages.

(b) *Discussion*.

The foregoing observations on the occurrence and distribution of glycogen in the placenta of *Crocidura caerulea* are found to be similar to a large extent to the observations recorded by authors on other mammals. A striking difference is that glycogen occurs in the syncytiotrophoblast in *Crocidura caerulea* and is absent from the uterine glands when compared to rodents (Wislocki, Deane and Dempsey, 1946) and to the bat, *Myotis lucifugus lucifugus* (Wimsatt, 1949). The similarity with the human placenta is, however, closer (Wislocki and Dempsey, 1948) because in both glycogen is observed in the syncytiotrophoblast. When compared to other insectivores, e.g., *Blarina brevicauda* and *Sorex fumeus* (Wislocki and Wimsatt, 1947), the presence of an abundant amount of glycogen in the placental labyrinth and of a less amount in the syncytiotrophoblast and of its complete absence in the uterine glands in this shrew indicate the main differences between these related species.

Wimsatt and Wislocki (1947) doubted Sansom's account of haemochorial nature of the placenta of *Crocidura caerulea*. They based their doubts on the illustrations in Sansom's paper (1937) and they had not in their possession the necessary material which they could examine to confirm their doubts. I propose to redescribe the placenta in a separate communication. It is, however, certain that there are considerable differences in the occurrence and distribution of glycogen in these insectivores. In *Crocidura caerulea* it is very much different from what it is in *Blarina* and *Sorex*.

During early stages of gestation in *Crocidura caerulea*, glycogen is observed in the cells lining the crypts and in the stroma but none in the uterine glands. The quantity of glycogen increases in the stroma up to mid-gestation and persists in undiminished quantities till term. A similar variation in quantity is observed in the decidual cells, in the cells of the bilaminar omphalopleure and in the yolk-sac splanchnopleure, showing that the yolk-sac wall is functional from the earliest stages of gestation till parturition. Glycogen is observed in the allantois after the trophoblast cells have eroded the cells lining the epithelial crypts and after a close relationship has been established between it and the maternal tissues. Here, however, glycogen increases in quantity in the allantoic mesenchyme and in the cytotrophoblast until a maximum quantity is observed and then persists in undiminished quantities till term. This also indicates that the yolk-sac is the first established foetal membrane for the nourishment of the embryo. Later, the allantois becomes functional and then both function concurrently till term. No glycogen has been observed in the cyto- and syncytio-trophoblast forming the trophoblastic sheath, though the foetal vessels contain abundant granules. Glycogen has been observed in both cyto- and syncytio-trophoblast of the placental disc.

The present histochemical study confirms certain conclusions arrived at on purely morphological grounds regarding the functional significance of foetal membranes and other structures during gestation. At the blastocyst stage it seems that glycogen is transferred from mother to embryo through the secretion of the uterine epithelium which forms crypts. Glycogen is observed in the lumen of the uterus and in the trophoblast of the bilaminar omphalopleure; particularly heavy concentrations of granules are present in the trophoblast cells which are concerned with the first fixation of the blastocyst to the uterine wall. At a slightly later stage, when the crypts have been partly eroded by the proliferating trophoblast cells the trophoblast of the bilaminar omphalopleure apparently derives glycogen from the glycogen-laden connective tissue cells either by phagocytic ingestion of those cells or by a transference of the substance to the cells of the trophoblast. The absence of glycogen

in the trophoblast of the chorion situated opposite the newly formed placental disc and in the placental disc itself probably indicates that the allantois has not as yet become functional as an organ of nutrition. From its occurrence and distribution from stage VI onwards it seems that the trophoblast cells of the bilaminar omphalopleure, particularly those on the lateral sides, absorb glycogen from the decidual cells (fig. 3) and from the extravasated maternal blood. Glycogen is observed in some places along the Reichert's membrane and in some cells of the endoderm of the bilaminar omphalopleure. It is also observed in a part of the endodermal villi of the yolk-sac splanchnopleure and omphalopleural vessels. This discontinuous distribution of glycogen is probably due to the absorbed material being digested by the cells of the trophoblast. The digested product then, is passed through the yolk-sac splanchnopleure and omphalopleural blood vessels. It is also possible that during the transmission of the digested product from the trophoblast cells a certain amount of resynthesis of glycogen may occur at some places which gives the glycogen reaction. But these conclusions are based more on general considerations rather than on direct evidence.

From mid-pregnancy onwards several kinds of trophoblast cells are found in the bilaminar omphalopleure. Large proliferating trophoblast cells are found on the placental disc, tall columnar ones are found on the lateral sides and cubical cells are found on the mesometrial side. Cells exposed to the uterine lumen are digitiform in character. All these contain glycogen and are similar in function in this respect.

In stage IX large quantities of glycogen are found in the cells of the endodermal villi and this probably coincides with the formation of blood cells which is taking place at a very rapid rate. Blood cells at all stages of development are seen and the presence of glycogen round such areas (fig. 4, *ov*) may prove to be an important factor in their formation.

At stage IV, glycogen is not observed in the epithelial crypts which in earlier stages contained a large amount of the substance. It would appear that the glycogen contained in the cells of the uterine epithelial crypts is absorbed by eroding cells from which glycogen is in its turn absorbed by the primitive blood cells and thus the violet granules are observed all the way up the allantoic stalk. The allantoic placenta becomes increasingly functional as a nutritive organ. Hence, glycogen granules occur more markedly in relation to the allantoic placenta. Glycogen is transferred from maternal blood vessels in the allantoic placental region through the allantoic mesenchyme and foetal blood. Glycogen can be found in abundance all along the allantoic stalk. That glycogen is passed to the embryo through the allantois is substantiated by the fact that the ventral part of the embryo (*i.e.*, on the mesometrial side) is loaded with a particularly heavy deposit of glycogen.

In conclusion, it may be said that the yolk-sac is the first foetal membrane to provide the growing embryo with glycogen. At a later stage the allantois becomes functional as a nutritive organ and then both function concurrently as organs of nutrition till term.

Numerous large granules are observed in the amnion from stage V onwards, the maximum number and largest size of granules being observed in stage VIII.

Significance of glycogen.—In discussing the significance of glycogen in the human placenta, Dempsey and Wislocki (1944) pointed out that it is deposited in regions which are poorly vascularized. From this and other considerations they concluded that glycogen deposition often occurs in tissues which are characterised by a low respiratory metabolism, and they suggested that anerobic glycolysis might provide a source of energy for oxidation in tissues having limited mechanisms for aerobic respiration.

In 1945 Wislocki and Dempsey working on the endometrium of pregnant rats, guinea-pigs, cats, sows and human beings showed that glycogen was absent from the endometrium of the sow both before and after implantation but that it occurred widely in decidually formed tissues in the rodents and man. In the cat, however,

glycogen occurred in places in the necks of the uterine glands and in the surface epithelium (Dawson and Kusters, 1944). These findings are in accord with their earlier hypothesis, and with the observations of other workers on changes in the endometrium wherever these are described. In the sow the blood vessels of the endometrium are not known to undergo destruction or compression or much lengthening. The circulation remains unimpaired. Hence glycogen is not deposited. On the other hand, the endometrium in rodents and man undergoes considerable change in which the blood vessels are destroyed and marked proliferation and thickening occurs.

On the basis of this hypothesis and from their observations Wislocki and Dempsey (1945) concluded that the placenta of the sow possessed an adequate circulation at all times and that glycogen deposition therefore did not occur. In man and rodents, however, great quantities appear in the decidually transformed sites. These transformations are the result of endometrial proliferation and thickening accompanied by manifestations of avascularity owing to the destruction of blood vessels and consequent physiological changes. In the cat glycogen was limited to traces which were present in the necks of the uterine glands and the surface epithelium in between placental sites. This would indicate an intermediate condition in which the blood vessels remain very nearly intact and a moderate amount of thickening and proliferation occurs.

Subsequent investigations appear to support this hypothesis. In the shrews, *Blarina brevicauda* and *Sorex fumeus* (Wislocki and Wimsatt, 1947) glycogen occurs in the uterine glands and surface epithelium just as in the cat. The placentation has been described as endotheliochorial (Wimsatt and Wislocki, 1947) and hence the blood vessels are not destroyed nor do they undergo any radical changes. Hence the shrews, like the cat, would appear to occupy an intermediate position with regard to changes in the endometrium and consequent deposition of glycogen.

In the bat *Myotis lucifugus lucifugus* (Wimsatt, 1949) glycogen is heavily deposited in the endometrium as in rodents. Intensive changes occur in this region comparable to changes which occur in the case of the rodents and the placentation has been described as haemochorial (Wimsatt, 1945).

Thus it seems that animals unrelated to each other may show a similar localization of glycogen. The sow would then be representative for animals having an epitheliochorial placentation, in which the glycogen deposition does not occur in the endometrium. The cat and the shrews, *Blarina* and *Sorex*, would represent types having endotheliochorial type of placentation and in the endometrium of which glycogen occurs in traces. The rodents, man and the bat, *Myotis lucifugus lucifugus*, would represent types having the haemochorial placentation and in the endometrium of which glycogen occurs abundantly.

Crocidura would then be classed in the last group along with the rodents, man and the bat, *Myotis*, since large quantities of glycogen are present in the endometrium. Purely on this basis the placenta seems to be of the haemochorial type, and this would then be in agreement with the hypothesis of Dempsey and Wislocki with regard to the distribution of glycogen, Sansom's observations and my own findings (Owers, 1951) which confirm Sansom's conclusions regarding the haemochorial nature of the placenta.

SECTION II—IRON.

(a) Observations.

The cells of uterine glands contain numerous blue granules. Diffuse blue coloration is seen in the secretion in the lumen of the glands. No iron was observed in the maternal tissues and in the blastocyst.

Myometrium.—Except in stage III and VIII, iron is indicated by the Turnbull blue reaction and is seen as a ring of blue present in the myometrium of the uterine

wall. The coloration is mainly diffuse but in places granules are evident. In stage VI these granules are present in large clumps and are most numerous. The number and the size of the granules gradually decrease towards term and they are absent in stage X.

Endometrium.—Large aggregates of blue granules are observed in the mid-term stages on the mesometrial side just beneath the uterine epithelium (fig. 6). In the uterine epithelium in stages VIII and X on the mesometrial side traces of iron are observed in a few cells. Iron is absent in the uterine glands in the late stages of gestation, but is present in the cells of the uterine glands in the early stages I and II.

Yolk sac placenta.—Traces of iron are observed in the decidual cells along the lateral sides of the uterus in contact with the trophoblast of the bilaminar omphalopleure, the maximum staining reaction being observed during mid-term in stage V, but is absent in stages VI, VIII and IX. No iron is observed in the early yolk sac until its invagination in stage II. From this stage onwards iron is observed in the parietal layer of the yolk sac in the trophoblast in the Reichert's membrane and in the endoderm of the bilaminar omphalopleure. In the visceral layer of the yolk sac iron is observed in the endodermal villi and in the mesoderm. Observing the yolk sac as a whole and in perspective with the yolk sac of other stages iron is observed to be present in great abundance in stage VIII. The presence of comparatively large amounts of iron in this stage in the yolk sac probably coincides with the haemopoietic activity of the yolk sac splanchnopleure. The primitive blood cells themselves give a strong blue colour indicative of the presence of iron.

Allanto-chorionic placenta.—Iron is absent in the allanto-chorionic placenta of early stages and in stage V and stage VI traces of blue coloration are observed in a few cells of the placental disc. In stage VIII, IX and X a faint and diffuse coloration is observed in the syncytiotrophoblast. In the late stages especially in stage IX the maternal and foetal blood 'lakes' in the placental disc give a pale blue coloration. Again in stages IX and X just before parturition blue coloration is present as a band between the placental disc and the myometrium along a line indicating the future separation of the placenta from the uterus.

The Amnion.—In stage VII it contains blue granules.

(b) Discussion.

Wimsatt (1949) discusses the modes of transmission of iron in different types of placenta in mammals and the importance of each source. The ultimate source of iron is the mother. It may be transmitted to the foetus in three ways: the secretion of the uterine glands, the extravasated blood or direct absorption of iron from red blood cells. The importance of each source depends on the ultimate placental barrier which is established. Iron has not been detected in the labyrinth of endothelio-chorial placentae (except in the case of *Crocidura caerulea* if Wislocki's contention is correct that it has a placenta of this type). Positive reactions have been observed in the yolk sac endoderm and this probably represents absorbed iron that originates from the uterine glands and from the extravasated maternal erythrocytes. In the case of the haemochorial type, iron has been detected in all placentae examined for it. In some cases no iron has been detected in the chorion indicating that the secreted iron from the uterine glands and from extravasated blood plays no part in the transmission. Finally, the transmission and patch localization of placental iron may depend on foetal circulatory deficiencies.

Wislocki and Dempsey (1945) observed iron in the uterine glands of the sow, guinea-pig and woman, during pregnancy, though in the non-pregnant uteri, iron was found to be absent. In the cat, however, no iron was observed in the uterine glands either before or during pregnancy. During gestation, the columnar chorionic cells (cytotrophoblast) in contact with the extravasated maternal blood (brown border) showed abundance of iron (Wislocki and Dempsey, 1946). This suggests

that in the cat as in other carnivores, the foetus receives its quota of iron from haematoma or extravasated blood, whereas in the sow, guinea-pig and woman; the uterine glands play an important part in the transmission of iron to the foetus.

My observations in the case of *Crocidura caerulea* agree with those of Wislocki and Dempsey. In the non-pregnant uterus iron is found to be absent, but in the pregnant uterus containing a blastocyst blue coloured granules were observed in the cells of the uterine glands and nowhere else thus indicating that the uterine glands play an important part in the transmission of iron in the early stages of placentalation in *Crocidura*.

In the sow, Wislocki and Dempsey (1946) observed that in the non-pregnant uterus no iron was present in the epithelial cells of uterine mucosa. The placenta is of the epitheliochorial type and in the foetal part of it an abundance of iron was present in the chorionic areolae and less in the chorionic ridges and fossae. It was also found to be present in the stroma of the chorion adjacent to the allantoic membrane. Iron appears to be transmitted in this case from mother to foetus through the secretion of the glandular epithelium, and is later absorbed through all parts of the chorion but mainly through the chorionic areolae.

In the cat (Wislocki and Dempsey, 1946), iron is absent in the uterine epithelium, in the uterine glands and in the placental labyrinth. It is present in the extravasated maternal blood and in the columnar chorionic cells in contact with these extravasations and in the extravasations in the junctional zone and in the basal cytotrophoblast. It is also present in the columnar epithelium and adjacent stroma of the para-placental chorion. In the dog, iron is present in the lumen of the uterus and adjacent chorionic epithelium in the region corresponding to the haematoma, in the para-placental and sub-placental regions. It seems that the foetus receives iron from the extravasated blood in these two carnivores, and that it is absorbed by a specialised area of the cytotrophoblast at the borders and at the base of the placenta (green and brown borders).

Wislocki and Wimsatt (1947) observed in the pregnant uteri of *Blarina brevicauda* and *Sorex fumeus*, the presence of iron in the cells of the uterine glands and in their lumina, and in the lateral mucosal cushions. Iron is also seen in groups of cells and in occasional interstitial spaces in the stroma of both myometrium and mesometrium and especially in the latter. Iron in the uterine stroma persists until term whereas that in the uterine glands gradually disappears. The Turnbull blue reaction is quite intense in the epithelium of the annular region, but it occurs in patches also in other regions of the membranous chorion. Traces of iron are also observed in the Reichert's membrane, parietal layer and lumina of the yolk sac and in its visceral wall as well. Iron is not demonstrable in the placental labyrinth of the chorio-allantoic placenta. To a large extent my observations on *Crocidura caerulea* agree with those of Wislocki and Wimsatt (1947) and it would seem that in early stages the embryo receives iron from the secretion of the uterine glands. Later, however, iron is absorbed by the yolk sac trophoblast from the extravasated blood in contact with it.

However, *Crocidura caerulea* differs from these two insectivores inasmuch as traces of iron are observed in some cells of the placental disc of the chorio-allantoic placenta and maternal and foetal blood gives pale blue coloration in late stages just before parturition. One is here reminded of the traces of iron observed in the haemochorial labyrinthine placenta of various rodents (mouse, rat, guinea-pig, hamster) by Wislocki, Deane and Dempsey (1946) where the Turnbull blue reactions in the placental syncytium was characterised simply as 'faint and diffuse'. This is interesting in view of Wislocki's remarks that the placenta of *Crocidura* is probably endotheliochorial which is characteristic for all insectivores so far studied and not partly haemochorial as described by Sansom (1937). It also differs from *Blarina* and *Sorex* and agrees with the bat, *Myotis lucifugus lucifugus* (Wimsatt, 1949) in that in the late stages both foetal and maternal blood give the Turnbull reaction.

The presence of traces of iron in the chorio-allantoic placental labyrinth in *Crocidura caerulea* would indicate a resemblance to the haemochorial, chorio-allantoic placental labyrinth of rodents in this respect.

Sansom (1937) reported that the brown granules in the pigmented cells of the yolk sac of *Crocidura caerulea* gave negative tests for iron. I have observed a similar negativity in this animal.

Wislocki, Deane and Dempsey (1946) observed traces of iron in the haemochorial labyrinthine placenta of various rodents (mouse, rat, guinea-pig, hamster), the Turnbull blue reactions in the placental syncytium being characterised simply as 'faint and diffuse'. Further the yolk sac entoderm exhibits relatively greater abundance of iron than the labyrinthine placenta and represents absorbed iron which originates both from the uterine glands and from extravasated maternal erythrocytes.

In the human placenta iron appears to be transmitted to the foetus through the syncytial trophoblast covering the chorionic villi in early pregnancy. In the second and third quarters of gestation iron is irregularly present in the para-syncytial stroma (Wislocki and Dempsey, 1946).

Wimsatt (1949) observed that in the bat *Myotis lucifugus lucifugus* iron was revealed most abundantly in the mesenchymal stroma of the labyrinthine placenta. Sporadic presence of iron was revealed by the Turnbull blue and Prussian blue reagents in the yolk sac entoderm, the chorionic trophoblast of a young implanted specimen and the endometrial stroma during implantation; positive reactions were nearly always given with these tests for foetal and maternal erythrocytes. A faintly positive Macallum reaction (for 'organic iron') is given in the syncytial trophoblast and it is concluded that the foetal iron in the bat is derived almost entirely from the maternal blood in the placental labyrinth. In this case the transmission and patch localisation of placental iron may depend on foetal circulatory deficiencies. Iron is localised in patches in the labyrinthine haemochorial placenta and tissues as gestation advances. This may be also partly due to the direction of flow of maternal blood through the placental tubules and to the varying width of the lumina of the trophoblast tubules.

Crocidura caerulea resembles *Myotis lucifugus lucifugus* as positive reactions with the Turnbull blue reagent were observed in the last two stages prior to parturition in the foetal and maternal erythrocytes. Traces of iron have also been observed in the syncytiotrophoblast in the case of *Crocidura*. But the two differ in the fact that in *Crocidura* the yolk sac appears to be the main organ for absorption of iron whereas in *Myotis lucifugus lucifugus* it is not.

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SUMMARY FOR GLYCOGEN.

1. The presence of glycogen has been studied in the placenta of *Crocidura caerulea* from stages I to X as described by Sansom (1937) with a view to implement earlier observations made on purely morphological grounds regarding the functional importance of the various uterine and foetal structures by histochemical tests.

2. The early blastocyst receives glycogen from the uterine epithelial crypts. Later the yolk sac obtains glycogen from the decidual cells by direct absorption and by phagocytosis.

3. Glycogen is observed in the syncytiotrophoblast and in the cytotrophoblast of the placental disc. It is transferred from maternal to foetal blood-vessels and from thence to the embryo via the foetal blood-vessels in the allantoic stalk. The yolk sac and the chorioallantoic placenta function concurrently as organs of nutrition of the embryo until term.

4. Although it is a shrew, *Crocidura caerulea* differs considerably from *Blarina* and *Sorex* in the occurrence and distribution of glycogen in that glycogen is not observed in the uterine glands and only traces are observed in the syncytiotrophoblast, and large quantities are present in the endometrium.

5. The presence of glycogen in the endometrium appears to be in accordance with the hypothesis of Dempsey and Wislocki and with Sansom's observations regarding the haemochorial nature of the placenta of *Crocidura caerulea*.

SUMMARY FOR IRON.

1. The presence of iron has been studied in the placenta of *Crocidura caerulea* from stages I to X as described by Sansom (1937) with a view to implementing earlier observations made on purely morphological grounds regarding the functional importance of various uterine and foetal structures by histochemical tests.

2. The early blastocyst receives iron from the uterine glands, at a slightly later stage iron is absorbed by the yolk sac from extravasated blood corpuscles and this appears to be the most important foetal organ for the absorption of iron, in the early stages of gestation.

3. The presence of iron in the syncytiotrophoblast in traces, and its presence in the maternal and foetal blood in the late stages indicates that the chorioallantoic placenta plays a part in the transmission of iron from the maternal to the foetal tissues.

4. *Crocidura* holds a peculiar position on the basis of the occurrence and distribution of iron in the placenta since it differs in some respects and agrees in others with observations made on the cat, shrews, rodents man and the bat, *Myotis lucifugus lucifugus*.

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EXPLANATION OF PLATE XX.

- FIG. 2. The photomicrograph shows a maternal blood vessel (*mbo*) on the antimesometrial side in the endometrium, the wall of which is loaded with glycogen granules. Taken from stage IV—Bauer-Feulgen. Myometrium (*myo*), connective tissue (*ct*).
- FIG. 3. Photomicrograph of a transverse section taken from stage VIII showing the decidual cells (*dc*), trophoblast (*tr*), Reichert's membrane (*rm*), endoderm of the bilaminar omphalopleure (*end*), and the endoderm of the invaginated vascular splanchnopleure (*end v spl*). The decidual cells contain numerous glycogen granules and also the endoderm of the bilaminar omphalopleure. Smaller numbers of granules are evident in the trophoblast and in the endodermal villi of the yolk sac splanchnopleure. Bauer-Feulgen.
- FIG. 4. Photomicrograph of a transverse section from stage IX. The yolk-sac splanchnopleure (*v spl*) contains glycogen. Large deposits of glycogen are particularly evident in the walls of the large omphalopleural blood vessel (*ov*), which contains primitive blood cells. Bauer-Feulgen. Trophoblast (*tr*), Reichert's membrane (*rm*) endoderm of the bilaminar omphalopleure (*end*), decidual cells (*dc*).
- FIG. 5. Photomicrograph of a part of the placental disc from the marginal region in stage VIII showing an abundance of glycogen granules in all the cellular elements both foetal and maternal, Bauer-Feulgen.
- FIG. 6. Photomicrograph of a part of the endometrium on the mesometrial side showing large deposits of iron beneath the uterine epithelium (*uep*). Ferricyanide technique. Connective tissue (*ct*).

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